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TAMPERE UNIVERSITY OF TECHNOLOGY

ANTTI NURMINEN

# A STUDY ON RELIABILITY DATA COLLECTION AND ANALYSIS

Master's thesis

Examiner: Professor Seppo Virtanen
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# ABSTRACT

**ANTTI NURMINEN**: A study on reliability data collection and analysis
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This thesis studied the maintenance data collection process of a container moving vehicle manufacturer, Kalmar. In addition, the data currently collected was analyzed in order to determine its usability for effective RAM analysis.

To understand the data collection process Kalmar's workshop in Vuosaari harbor, Helsinki Finland was visited and Kalmar reporting manuals explored. The process was found too heavy for effective maintenance reporting. To complete a work report, the system needs at least 100 inputs on the mouse or keyboard. Those inputs are across 35 screens so users spend much of their time moving from one screen to the next.

The Vuosaari workshop reported that after adopting the system called SAP for maintenance reporting the time they spend on reporting has increased by 40 hours per month. It means they have one week less every month to spend on activities other than reporting. This is a huge increase in reporting time even if you take into consideration that during this time their maintenance work has experienced a growth of 25%.

The added time for reporting has not lead to high quality reports. The tools in SAP to input key parameters such as hour counter readings aren't used, but instead open text fields are used. This is problematic for RAM analysis, because of the difficulty to effectively filter open text information. Thus effective RAM analysis is not viable since work orders have to be opened one at a time to collect the information.

Moreover, the heavy process has led to other practices that decrease the usability of the data. One such practice is to open a single work order per month per machine and then write all the maintenance work done during the month under that same work order. This has the effect of hiding the true amount of failures the machines have experienced – unless the information is extracted by reading work reports one by one.

To improve the usability of SAP, this thesis presents some choices. One approach is to redesign the layouts so only necessary inputs and few screens are needed. However, to achieve this, new software, such as SAP Screen Personas, is needed. Mobile reporting tools could help technicians report to SAP immediately after maintenance is complete or even during maintenance. Moreover, considering that it takes from 8 to 9 days to manage all the reporting activities during a month, the idea of hiring more help to specifically handle the reports should be considered as well.

# TIIVISTELMÄ

**ANTTI NURMINEN**: A study on reliability data collection and analysis
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Tässä diplomityössä tutkittiin kontinsiirtolaitteita valmistavan yrityksen, Kalmarin, huoltotietojenkeräysprosessia. Lisäksi selvitettiin kerätyn tiedon soveltuvuutta luotettavuusanalyysiin.

Tietojenkeruuprosessin tutkimista varten tehtiin vierailu Kalmarin työpajaan Vuosaaren satamaan Helsinkiin ja käytiin läpi Kalmarin ohjeistus huoltotietojen raportointiin. Prosessin havaittiin olevan liian raskas tehokkaaseen huoltotietojen raportointiin. Jotta työn saa raportoitua, järjestelmälle tulee antaa vähintään 100 syötettä hiirellä tai näppäimistöllä. Syötteet on jaettu 35 eri ruudulle, joten raportointiajasta suuri osa kuluu ruudusta toiseen siirtymiseen.

Huoltoraportointiin kuluva aika on lisääntynyt Vuosaaren työpajalla 40 tunnilla sen jälkeen, kun toiminnanohjausjärjestelmä SAP on otettu käyttöön. Huoltohenkilöillä on siis viikko vähemmän aikaa korjata koneita. Vaikka otetaan huomioon, että he tekevät 25% enemmän korjaustyötä kuin aikaisemmin, on raportointiin kuluva ajanlisä valtava.

Raportointiin käytetty lisäaika ei kuitenkaan ole tuottanut korkeampilaatuisia työraportteja. Käyttötuntien määrittämiseen ei käytetä SAP:n työkaluja vaan tiedot kirjataan vapaisiin tekstikenttiin. Tämä on ongelmallista luotettavuusanalyysin kannalta, koska vapaasta tekstistä on vaikea suodattaa tietoa. Tehokas luottavuusanalyysi ei ole käytännössä mahdollista, koska työraportit on aukaistava ja luettava yksi kerrallaan.

Raskas prosessi on lisäksi johtanut toisiin käytäntöihin, jotka vähentävät tiedon käytettävyyttä. Yksi tällainen käytäntö on avata koneelle joka kuukausi yksi työilmoitus johon kirjoitetaan kaikki sen kuukauden aikana koneelle tehdyt huollot. Tämä käytäntö piilottaa koneen vikaantumisten määrän – ellei niiden määrää selvitetä työraportteja yksi kerrallaan lukemalla.

Tässä työssä esitetään muutamia ehdotuksia SAP:n käytettävyyden parantamiseksi. Yksi keino on SAP:n käyttöliittymän uudelleensuunnittelu siten, että vain tarpeelliset syötteet säilytetään ja sijoitetaan muutamalle ruudulle. Tämän saavuttaminen vaatii kuitenkin lisäohjelman, kuten SAP Screen Personasin. Raportointi voisi myös helpottua mukana kannettavilla raportointityökaluilla, joilla työraportti voitaisiin kirjata työn valmistuttua tai työtä tehdessä. Ottaen huomioon raportointiin kuluvan aikaa 8 – 9 päivää kuukaudessa, tulee harkita myös lisätyövoiman palkkaamista raportointitaakkaa keventämään.

# PREFACE

This thesis was written in Kalmar at the Tampere Technology and Competence Center. I would like to thank the head of the maintenance development team, Vincent Josse, for his input and advice on this thesis. I would also like to thank reliability engineer Kati Kivimäki who helped me in all things related to Kalmar on a practically daily basis. The now retired Keijo Anttonen gave valuable insight from the viewpoint of service and maintenance.

The employees at Kalmar workshop at Vuosaari have my thanks for their straightforward sharing of opinions. Especially service manager Perttu Kojonen provided me with key information on several occasions. Jari Keyriläinen helped me understand the current ERP system. Also a host of others in Kalmar assisted me along the way and I wish to thank all of them as well.

While Kalmar gave me the chance to write my Master's thesis, the examiner, Professor Seppo Virtanen gave me the inspiration to do so. His lectures on reliability engineering at the Tampere University of Technology carried a single flaw - there were too few of them. I hope I will have the chance to learn from him in the future as well.

Most importantly, I want to thank my wife Kirsi for the support she has given me – not only during this thesis, but during all of our years together. Home is where she is.

At Tampere, 23 June 2015

Antti Nurminen

## CONTENTS

## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| ASC | Automated Stacking Crane |
| EMEA | Europe, Middle-East and Africa |
| ERP | Enterprise Resource Planning |
| f(t) | Probability density function, derivative of F(t). |
| F(t) | Cumulative distribution function. The probability that the item will fail within time interval [0, *t*]. |
| Hour counter | Counter for the operating hours of a machine. |
| Input | Command executed or information added by keyboard or by mouse |
| MDT | Mean Downtime, the mean time of failure start to failure end. |
| MMDT | Mean Maintenance Delay Time |
| Module | In SAP, training manuals are divided into modules that give instructions to specific tasks, e.g. Create Service Notification module. |
| MTTF | Mean Time To Fail |
| MTTR | Mean Time To Repair |
| NPD | New Product Development |
| PDA | Personal Digital Assistant |
| PO | Purchase Order |
| PRA | Probabilistic Risk Assessment |
| R(t) | Reliability function = 1 – F(t) |
| RAM | Reliability, Availability and Maintainability |
| RAMS | Reliability, Availability, Maintainability and Safety |
| RTG | Rubber-Tyred Gantry Crane |
| SAP | The Enterprise Resource Planning (ERP) program used by Kalmar. |
| STS | Ship-To-Shore crane |
| z(t) | Hazard function; f(t) divided by R(t) |

# 1. INTRODUCTION

This thesis is a study on the reliability data collection and analysis of a cargo container moving vehicle manufacturing company, Kalmar. The thesis determines the current process of reliability data collection and also analyses the types of data collected and their usability in terms of dependability analysis. This is done by using Kalmar's Vuosaari maintenance workshop as a case example and with further information from internal reporting guidelines. This thesis also discusses the quality deficiencies of the maintenance data currently collected by Kalmar technicians.

This chapter contains an introduction to Kalmar and its Enterprise Resource Planning system called SAP. In Chapter 2 reliability engineering is discussed while Chapter 3 describes the current situation of maintenance reporting at the Kalmar workshop in Vuosaari harbor, Finland. Chapter 4 contains a description of the reporting process in SAP and lists consequences of the poor process flow. Chapter 5 looks at ways to improve maintenance data collection and in Chapter 6 is the conclusion for the thesis.

## 1.1 Introduction to Kalmar

Kalmar is a provider of cargo handling solutions and services to ports, terminals, distribution centers and to heavy industry. In 2014, Kalmar's sales totaled 1.5 billion euros and it employed 5200 people globally. Kalmar is a part of Cargotec, a company listed in the Helsinki Stock Exchange. Cargotec's sales in 2014 were 3.4 billion euros with 11000 employees (Cargotec Corporation 2015).

Kalmar manufactures a wide variety of cargo moving vehicles and services related to terminal operation. Most of the machines are shown in Figure 1.1: Ship-To-Shore (STS) cranes, Automated Stacking Cranes (ASC), Rubber-Tyred Gantry (RTG) Cranes, Straddle Carriers, Shuttle Carriers, Reachstackers, Empty container handlers, Terminal tractors and Forklift trucks. Kalmar also manufactures Log Stackers although they are not shown in the figure. Kalmar and its affiliate companies also offer terminal operating software, automation solutions, bulk handling, spreaders, spare parts, crane upgrades and maintenance.

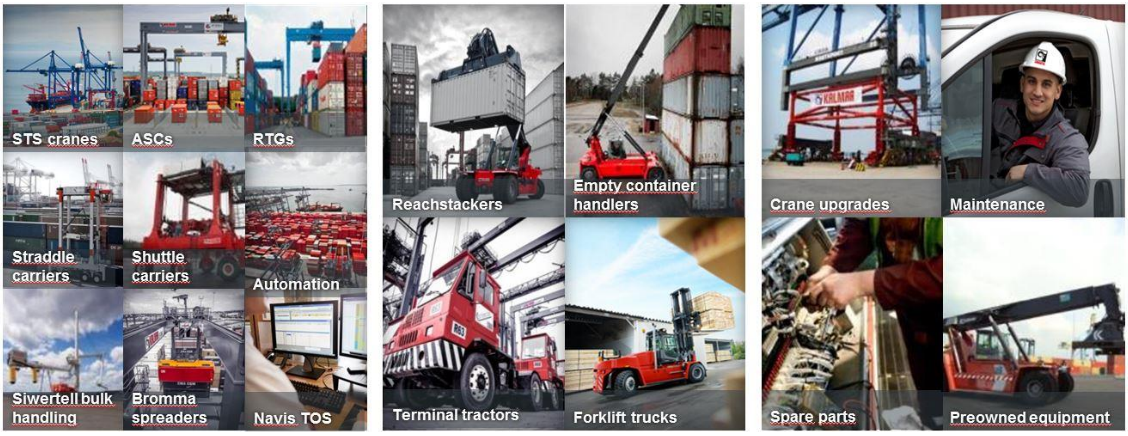



***Figure 1.1.*** *Kalmar machines and services.*

### 1.1.1 Maintenance in Kalmar

With a fleet of 38000 machines worldwide there is significant demand for effective maintenance. To manage all maintenance activities, Kalmar has workshops in 31 countries around the world. In addition, several technicians work outside of a workshop, travelling to the customer location when needed. At the end of 2014, the number of technicians working for Kalmar was about 1200.

The technicians mostly maintain Kalmar machines, but also other manufacturers' machines. In addition to failure repairs, their maintenance work includes preventive maintenance tasks based usually on the hour counter reading of the machine and refurbishment and replacement work.

### 1.1.2 Possibilities of RAM analysis in Kalmar

While Kalmar has extensive experience in maintaining cargo handling equipment there are possibilities for development. Reliability, availability and maintainability (RAM) analysis on the machines could pinpoint deficiencies and targets for developing the machines. RAM analysis also helps in predicting failures of the machines, plan spare part levels and estimate maintenance work costs. This information can for example be used when calculating machine lifecycle costs and the price of service contracts.

However, in order to provide a solid base for RAM analysis, there needs to be a consistent way of reporting failure (i.e. maintenance) data. However, as the real value in maintenance work is not in reporting, but in repairing, reporting must be made as easy as possible without losing much of the valuable information available. This thesis studies the maintenance data collection process in Kalmar, specifically in the Vuosaari workshop at Helsinki, Finland.

## 1.2 SAP

SAP is an Enterprise Resource Planning (ERP) program. Wikipedia describes ERP as business management software that enables the collection, storage, management and interpretation of data from different business activities (Wikipedia 2015). When all information is stored in one location, employees know where to report information and where to search it from.

In this thesis SAP is considered from the viewpoint of collecting maintenance data. While Kalmar technicians are used to reporting their work, they have seen issues with SAP. This is because it has been experienced that SAP hasn't been developed with the purpose of making maintenance reporting easier. In Chapter 3 it is stated that as a result of adopting SAP, the time reporting takes has increased by 200%. Therefore the learning of a new reporting system and process has not been met with celebration.

Furthermore, this is not the first time the technicians have been asked to adopt a new reporting system. In 2006, Kalmar began implementing a reporting system called KEOPS (Kalmar Enterprise Organizer for Profitable Service) that also required the technicians learn how to use the then new system for maintenance reporting. Now they are required to learn SAP.

The first thing an SAP user learns is that it's used with transactions. Each transaction is initiated with a specific code of numbers and/or letters and has specific functionality. For example in maintenance reporting, one transaction is used to report a machine's hour counter reading while others are used to notify when maintenance work has been undertaken and what costs were incurred during it. Some transactions are needed to report the need for maintenance work while some are used for the invoicing of work.

Employees of Kalmar have access to an SAP training library where the maintenance reporting process is divided into separate modules. For example, a module called "Create Measuring Document –module" describes how to report machine hour counter readings. Same kind of modules can be found for all stages of maintenance reporting, starting from creating a service notification (Create Service Notification module) and ending in the invoicing of work (Create Billing Document module).

While SAP allows the reporting of data, it also has several search functions for filtering the data from the system. It is for example possible to search all work orders for a specific machine type, see what their hour counter reading was at time of failure, what was the cause and the consequence of the failure and how it was repaired. Or you can for example go through used spare parts and list them in a table to see what parts were consumed the most or which had the most costs related to them.

While the search functions can be used to filter out different useful information, it has to be noted that they are only valuable, if the information is reported in the right manner.

This means that in order to effectively filter out hour counter readings of machines, the hour counter readings have to be marked in the Measuring Document where SAP knows to look for them. It is also possible to report hour counter readings and any other information into open text fields that have no automated search functions related to them.

So while SAP offers the tools for searching through the information in SAP with different filtering options, they aren't of use, unless the information is reported using the proper SAP modules. Furthermore, while there are several search functions within SAP, Cargotec has developed more search tools with a third party software supplier called Qlikview to extract the SAP data from a business warehouse and to visualize it. This allows Cargotec more control over the data extraction as changes to search routines are faster to do in the third party software than in SAP.

# 2. RELIABILITY ENGINEERING

The role and responsibilities of reliability engineering are discussed in several articles and books. O'Connor and Kleyner state that reliability engineering is first and foremost the application of good engineering, in the widest sense, during design, development, manufacture and service (O'Connor & Kleyner 2012, p.2). Hameed et al. see the role of reliability studies to offer tools for decision support (Hameed et al. 2011).

Mettas on the other hand defines reliability engineering as a combination of practical experience, maintenance, safety, physics and engineering (Mettas 2013). He says that in reliability engineering observational data is combined with experience to create models in order to control the behavior of the equipment, optimize its performance, and minimize the life cycle and operational costs.

On the prevention of failures, Barnard thinks engineers should always ask whether failures could have been prevented (R.W.A. Barnard 2008). He goes on to claim that all failures can be prevented in theory and almost always in practice. This is because all failures have root causes that can be removed once identified. Furthermore Barnard thinks too much time is spent on counting and managing failures instead of preventing them and states "reliability is the result of good engineering and good management, never the result of good accounting".

Zio defines reliability engineering as a scientific discipline that studies why systems fail, how to develop reliable systems, how to measure and test reliability and how to maintain reliability by maintenance, fault diagnosis and prognosis (Zio 2009). He also states the problems that afflict reliability engineering are related to the representation and modeling of the system, quantification of the system model and the representation, propagation and quantification of the uncertainty in system behavior.

In this chapter, research related to the field of reliability engineering is looked at. Chapter 2.1 looks at the role of management in reliability engineering development. Chapter 2.2 looks at research on the importance of customer retention and Chapter 2.3 links customer retention with employee retention. In Chapter 2.4 the importance of competing with quality is visited and Chapter 2.5 discusses what quality means in reliability engineering. Chapter 2.6 introduces the dependability parameters and Chapter 2.7 discusses the level of detail in reporting. Chapter 2.8 lists information required for reliability engineering analysis and Chapter 2.9 talks about reliability engineering in new product development process.

## 2.1 Role of management in reliability engineering

O’Connor and Kleyner state that while the mathematical and statistical methods in reliability engineering are limited, the over-riding benefit is the management of the reliability engineering effort (O’Connor & Kleyner 2012, p.2). According to them, reliability engineering is effective management of engineering.

They further expand on this stating that since reliability is a critical parameter and failures are due to errors by design and maintenance, reliability can only be maximized by an integrated effort (O’Connor & Kleyner 2012, p.2). While a reliability engineering specialist can provide support, training and tools, if management doesn’t drive the reliability effort, it can become a meaningless exercise.

The importance of high management level participation is repeated in a study describing best practices for effective reliability program plans (Carlson et al. 2010). The study states that in order to create a successful reliability program plan it not only needs the support from high management, it has to be understood by all employees. Otherwise it is unlikely the program will succeed.

Madu also stresses the importance of top management stating their commitment and involvement is crucial to a successful implementation of a maintenance and reliability program (Madu 2000). Moreover, Ledet adds that improvement in reliability is achieved by a change in organization culture of defect elimination (Ledet 1999).

Ledet goes on to describe the effects of the Manufacturing game workshops where personnel get to experience the role of operations, maintenance and business services, including stores and logistics (Ledet 1999). He states the workshops helped build a culture of defect elimination that led to significant improvements in reliability and reductions in maintenance costs. As an example, in Eastman Chemical, the savings are reported to be in excess of 500,000$ per year.

## 2.2 Importance of customer retention

Customer retention is discussed by Reichheld et al. who state car companies serious about measuring the value they deliver are interested in customer retention, not satisfaction (Reichheld et al. 2000). This is because customer satisfaction surveys are influenced by corporate desire for high satisfaction scores. High scores may be achieved, but by ways that don’t improve customer value. This has also been found by Heskett et al. (Heskett et al. 1994). Kandampully agrees by saying the measure of customer satisfaction is insufficient in creating loyal relationships (Kandampully 1998).

Kandampully also finds that the yardstick for measuring an exceptional service organization is its returning customer ratio (Kandampully 1998). He continues that while service organizations try to win the loyalty of customers, the customers are also looking for loyal service organizations – those that are able to offer superior quality service on a consistent basis. Therefore customer retention rate should be used as the measure of product and service value. Reichheld et al. found that a 5% shift in customer retention resulted in a 25-100% shift in profit (Reichheld et al. 2000).

Heskett et al. describe the value of a customer as “astronomical” as they describe what they call the service-profit chain (Heskett et al. 1994). Figure 2.1 shows the service profit chain which connects profitability, customer loyalty and employee satisfaction, retention and productivity. This is explained by profit and growth generated from customer loyalty while customer loyalty is a function of customer satisfaction.

Customer satisfaction is influenced by the value of service provided which is a function of employee retention and productivity. They in turn increase with the increase of employee satisfaction. Employee satisfaction results from high-quality support services and policies that enable them to deliver results to customers.

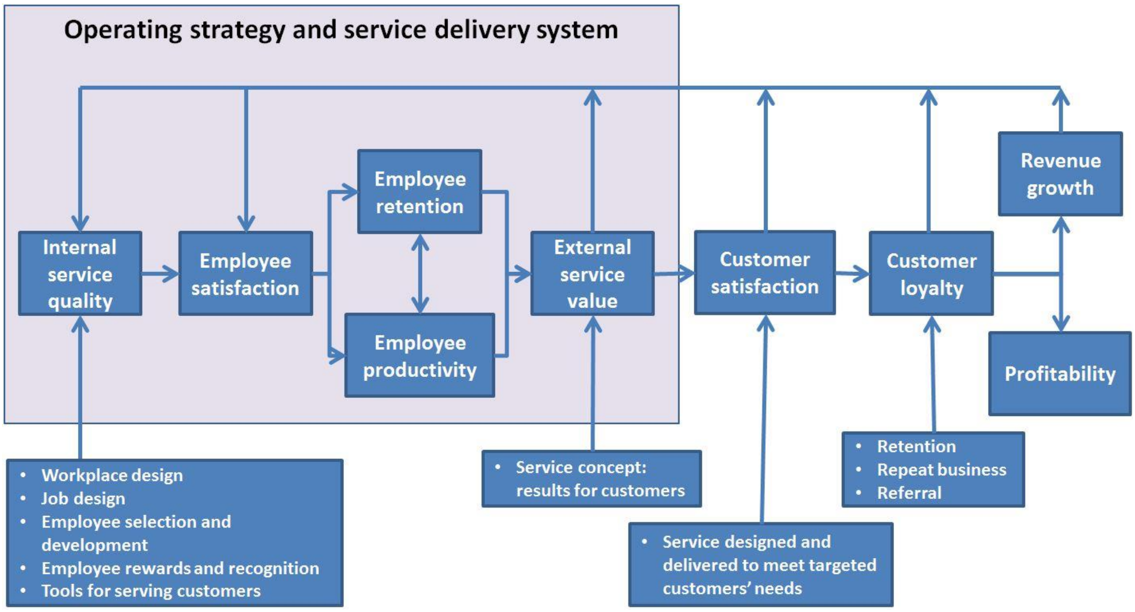



***Figure 2.1.*** *The service-profit chain, adapted from (Heskett et al. 1994).*

The connection of employee satisfaction and employee retention that Heskett et al. make (Heskett et al. 1994), is highly interesting. This is because there is research to support the positive correlation between employee retention and customer retention which is discussed next.

## 2.3 Employee retention and customer retention

Heskett et al. describe a situation where a property-and-casualty insurance company found the link between employee satisfaction and loyalty (Heskett et al. 1994). They also found that job satisfaction was primarily due to the employees’ perception of their ability to meet customer needs. Furthermore, the same study found that when a service worker left the company, customer satisfaction levels dropped sharply from 75% to 55%.

These same mechanisms were discovered by MCI in their 7 telephone customer service centers. It was seen that employees' perceptions of the quality of MCI service and employee satisfaction were linked. The study also found a link between employee satisfaction and customer satisfaction and loyalty (Heskett et al. 1994).

Taco Bell on the other hand has discovered that their stores with the lowest employee turnover rates enjoy double the sales and 55% higher profits than the 20% of stores with the highest employee turnover rates (Heskett et al. 1994).

Reichheld also finds that employee retention is a key factor in customer retention, because the value of employees grows as they gain more experience on working with customers (Reichheld et al. 2000). Chatterjee states high employee turnover rate increases cost of recruitment and training and it also affects customer service adversely (Chatterjee 2009).

In case of Kalmar, the service technicians are the ones that repair the machines of Kalmar's customers and are often in direct contact with the customers themselves. Reichheld adds that the importance of employee retention is what companies usually fail to recognize when trying to increase customer loyalty (Reichheld et al. 2000).

## 2.4 Competing with quality vs. pricing

If we take away the personal bond between long-term employees and customers, customer retention ability can be narrowed down to pricing and product quality. Moreover, as pointed out by Fornell (Fornell 1992), being unable to compete in quality will force the company to compete on price.

Fornell continues that this was observed for example in the automobile industry where U.S manufacturers came to rely on promotions while Japanese manufacturers focused on improved quality (Fornell 1992). On the other hand, a study by Hallowell was not able to establish the connection between price satisfaction and customer loyalty from data collected from 12000 retail-banking customers (Hallowell 1996).

Moreover Fornell states that while promotions have a negative effect on gross margins, focus on quality will have the opposite effect on the margins giving less need for price promotions (Fornell 1992). Furthermore Reichheld states that those who buy at the standard price are more loyal than those who buy on price promotion and that pricing should be employed to filter out precisely those customers who look for price promotions (Reichheld 2000).

Therefore, research supports the idea of competing on quality, not on pricing. Developing quality will increase customer retention, without having to resort to price promotions. Focus on quality and avoiding price promotions will not only help the company keep hold of loyal customers, it will also help get rid of those unlikely to be loyal. With the need for quality established one needs to look at what is meant by quality.

## 2.5 Quality in reliability engineering

In the ISO 8402 standard, quality is defined as "*The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs*" (ISO 8402). The Warwick Manufacturing Group state poor quality is something that the customer will quickly determine after purchasing the product. Either the product does not work as intended or breaks as soon as it's put to use (Warwick Manufacturing Group 2007).

Poor reliability on the other hand is seen as something that shows as time goes by or "quality over time". The product is considered poor reliability if it fails before it was reasonable for the customer to expect (Warwick Manufacturing Group 2007).

As Østerås et al. state, poor product reliability results in frequent failures (Østerås et al. 2005, p.75). The average consumer is aware of reliability issues in smartphones and cars and will consider a high-maintenance product to be of poor quality. In the container moving industry, a lack of reliability will lead to longer unload times of vessels and harbor efficiency will decrease. More than a decrease in efficiency, poor reliability has the potential to hurt customer retention rates as customers move to more reliable products offered by competitors.

In the people moving industry a risk aversive attitude has been found. In a study on public transport chains in the Netherlands, it was estimated that the price of a certain time loss of 1 minute is 27 cents whereas the valuation of a 50% probability of a 2 minute delay is 64 cents (Rietveld et al. 2001). While there is no direct comparison between the people and container moving industries, it can be thought that port terminal operators will also pick certain over uncertain when time loss is considered as uncertainty will lead to increased need of management on the fleet of container moving vehicles.

Kandampully references a study by Timmers and van der Wiele (Kandampully 1998) who state that it is not enough to satisfy the customer. They claim that in order to achieve competitive advantage, there is "a compelling need to delight the customer". They go on to say that in order to reach this, service organizations need to undertake continuous service innovation to transform its dormant assets into greater value to both the customer and the organization. The dormant assets discussed are service elements which include technology, service processes, environment and people.

Some of the key features and characteristics for customers in the container moving industry are the dependability parameters – reliability, availability and maintainability of the equipment. As Murthy et al. state, unreliability reduces availability and increases maintenance costs over the useful life of the product (Murthy et al. 2009). Hameed et al. also link reliability and quality (Hameed et al. 2011). They say reliability may perhaps be the most important quality characteristic.

In the container moving industry, terminal operators have the need to unload vessels as quickly as possible as cost effective as possible. Lack of dependability of the machines will inevitably lead to these needs not being satisfied. Therefore reliability and availability of the whole container moving chain is high priority to terminal operators and this should be noted by manufacturers of container moving machines.

Moreover, as Madu states, in order to be dependable a company has to use materials and resources effectively (Madu 2000). Therefore the improvement will be already seen on the production line with reduced costs and in the spare parts inventory that will be reduced. Production costs will go down which gives a competitive edge to the company.

The dependability of machines is not perfect, they all fail on occasion. To combat this terminal operators employ a fleet large enough to sustain a number of broken down container moving equipment. The more they break, the more machines are needed to act as spares for the broken ones. Vice versa, the more reliable the machines are the fewer machines the customer will need and the smaller the amount of money invested in equipment.

Moreover, the more reliable the equipment, the less the harbor operator has to improvise around failures. Being able to rely on their machines is valuable for operators of any machines. The less they have to worry about their machines the more they are able to concentrate on other areas of operation. Therefore, when it comes to customer retention through good quality products, one cannot overlook the effect of reliability on customer experience.

The effects an increase in dependability has on production costs, required fleet size and on the need for improvisation around failed equipment is summarized in Figure 2.2.

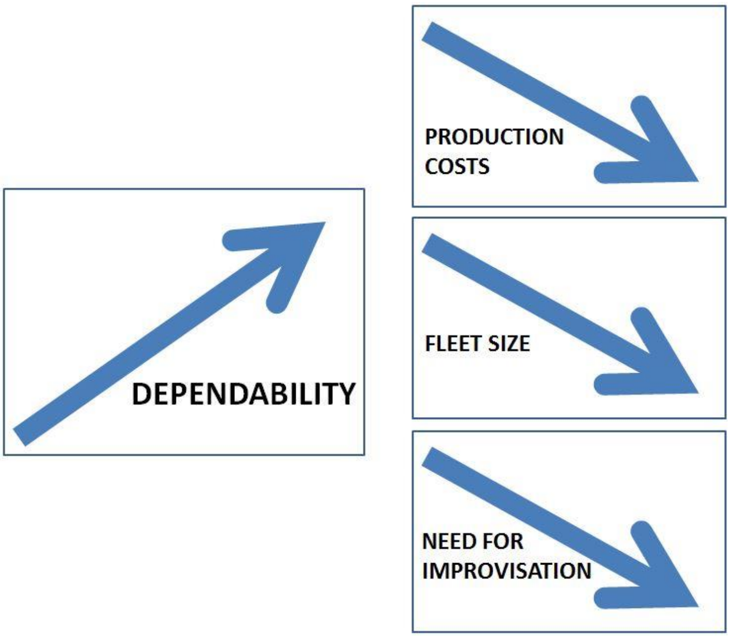



***Figure 2.2.*** *As dependability is increased, production cost, required fleet size and the need for improvisation around failed equipment goes down.*

The need for dependability is only enhanced with the increased use of automated machines. Automation increases because of two main drivers. The first driver is the reduction in operating cost. Skilled labor is hard to come by and the training of employees will lead to a salary increase. On the other hand, in some countries corruption runs high and employees sometimes reject work tasks unless they are paid extra. The second driver is the effect it has on terminal throughput.

Two studies on terminal throughput (Liu et al. 2002; Liu et al. 2004) simulated the use of automated guided vehicle systems on container terminal systems and estimated the average cost per container value of automated terminals. The simulation results were validated with real life operational data from the Norfolk International Terminal, USA. They found terminal throughput could be doubled and average container cost halved with use of automated guided vehicles.

As the use of automation increases, we will see longer and longer automated chains of container movers. Longer chains mean more possibilities for failure and greater need for increased dependability. It is therefore easy to see that dependability will be of great value to the customer and therefore it needs to be continually developed.

However, if we do not have a well-defined way of evaluating our current dependability level, we do not know how much need there is for development. It is said you can’t develop what you can’t measure. If we can’t measure dependability parameters we won’t know if we have made any progress by making changes to the way we do things.

Reichheld et al. (Reichheld et al. 2000) state that “What a business measures shapes employee thinking, communicates company values and channels organizational learning.” When there is a desire to improve dependability, a decision must be made to start measuring dependability parameters. This way the current dependability status will be known and direction for development can be determined. By measuring dependability, a company sends the message that it regards reliability to be important and that it also wants its employees on board.

This is further enhanced by Desa and Christer who describe a case from an inter-city bus company (Desa & Christer 2001). They found that reliability modelling contributed directly and indirectly to the improvement of the company’s operation and its maintenance function even though there was little failure data to work with. The benefits observed did not come as a result of quantitative analysis, but from the act of conducting the study.

The study brought forwards maintenance related problems within the company and helped change the attitude of the company towards a more maintenance oriented one (Desa & Christer 2001). This resulted in less bus breakdowns on the road and also directed management from an intuition driven decision process to a more rational and objective based process.

In a paper describing how Reliability, Availability, Maintainability and Safety (RAMS) -centric forecasts are used in decision support at Rolls-Royce, the writers state that one thing you can guarantee about a forecast is that it will be wrong (Rees & Van Den Heuvel 2012). However they have found forecasting useful from a quality improvement or robust design perspective, developing an understanding of how and why the system performs as it does.

Furthermore, Apostolakis states that while there is a presumption that Probabilistic Risk Assessment (PRA) should get the numbers right immediately, it is the impact it has on decision making that matters, not if it is able to produce accurate numbers (Apostolakis 2004). Apostolakis continues that decision making will be better with peer reviewed quantitative information as has been shown in the nuclear industry.

Thus, if a company is struggling with limited failure data that makes extensive analysis next to impossible, there are still benefits to achieve. Naturally, the more information there is to be analyzed the better. However, simply making a managerial decision to push for increased dependability will lead to increased dependability by making changes to the company reliability culture – even without extensive information available for quantitative analysis.

Murthy et al. state that one way to assure customers of high product reliability is through warranty (Murthy et al. 2009).  Warranty gives an indication of product reliability and can be bundled with the product as an element of product support. This is also a way of differentiating the product from competitors. Therefore further need for investment in product reliability is implied.

## 2.6 Dependability factors

Dependability is defined as: *The collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance* (IEC 60300).

RAM is a common abbreviation for reliability, availability and maintainability. Rausand and Hoyland define these dependability factors as follows in chapters 2.6.1 and 2.6.2 (Rausand & Hoyland 2004):

### 2.6.1 Reliability

The ISO 8402 standard defines reliability as: *The ability of an item to perform a required function, under given environmental and operational conditions and for a stated period of time* (ISO 8402).

Reliability is defined by the reliability function which tells the probability that the item will not fail in time interval [0, *t*]. The reliability function can be written as

$$\mathrm{R}(t) = 1 - \mathrm{F}(t) = \Pr(T > t) \quad \text{for t} \geq 0 \tag{1}$$

where F(*t*) is the distribution function that denotes the probability that the item will fail within time interval [0, *t*]. T is a random value for failure. The distribution function F(*t*) can be written as

$$F(t) = \Pr(T \leq t) = \int_0^t \mathrm{f}(u)\mathrm{du} \quad \text{for } t \geq 0 \tag{2}$$

where f(*u*) is the probability density function which is defined as

$$\mathrm{f}(t) = \frac{d}{dt}F(t) = \lim_{\Delta t \to 0} \frac{\mathrm{F}(t + \Delta t) - \mathrm{F}(t)}{\Delta t} = \lim_{\Delta t \to 0} \frac{\Pr(t < T \leq t + \Delta t)}{\Delta t} \tag{3}$$

Therefore the reliability function (1) can also be written as

$$\mathrm{R}(t) = 1 - \int_0^t \mathrm{f}(u)\mathrm{du} = \int_t^\infty \mathrm{f}(u)\mathrm{du} \tag{4}$$

If the item has not failed until time *t*, the probability that the item will fail within the time interval (*t*, *t* + Δ*t*) is

$$\Pr(t < T \leq t + \Delta t \mid T > t) = \frac{\Pr(t < T \leq t + \Delta t)}{\Pr(T > t)} = \frac{\mathrm{F}(t + \Delta t) - \mathrm{F}(t)}{\mathrm{R}(t)} \quad (5)$$

By dividing this probability by the length of the time interval, Δt, and letting Δt → 0, we get the failure rate function z($t$) of the item (=hazard rate)

$$\mathrm{z}(t) = \lim_{\Delta t \to 0} \frac{\Pr(t < T \leq t + \Delta t \mid T > t)}{\Delta t} = \lim_{\Delta t \to 0} \frac{\mathrm{F}(t + \Delta t) - \mathrm{F}(t)}{\Delta t} \frac{1}{\mathrm{R}(t)} = \frac{\mathrm{f}(t)}{\mathrm{R}(t)} \quad (6)$$

The relationship between function F($t$), f($t$), R($t$) and z($t$) are presented in Table 2.1.

***Table 2.1.*** *Relationships between F(t), f(t), R(t) and z(t), adapted from (Rausand & Hoyland 2004, p.20).*

| Expressed by | F($t$) | f($t$) | R($t$) | z($t$) |
|---|---|---|---|---|
| F($t$) = | - | $\int_0^t f(u)du$ | $1 - \mathrm{R}(t)$ | $1 - e^{-\int_0^t f(u)du}$ |
| f($t$) = | $\frac{d}{dt}F(t)$ | - | $-\frac{d}{dt}R(t)$ | $z(t) \cdot e^{-\int_0^t f(u)du}$ |
| R($t$) = | $1 - \mathrm{F}(t)$ | $\int_t^\infty f(u)du$ | - | $e^{-\int_0^t z(u)du}$ |
| z($t$) = | $\frac{dF(t)/dt}{1 - F(t)}$ | $\frac{f(t)}{\int_t^\infty f(u)du}$ | $-\frac{d}{dt}\ln R(t)$ | - |

## 2.6.2 Availability

*The ability of an item (under combined aspects of its reliability, maintainability and maintenance support) to perform its required function at a stated instant of time or over a stated period of time* (BS 4778).

Rausand and Hoyland go on to say we may distinguish between availability A($t$) at time $t$ and the average availability $A_{av}$ (Rausand & Hoyland 2004, p.6). The availability at time $t$ is

$$\mathrm{A}(t) = \Pr(\text{item is functioning at time } t) \quad (7)$$

The term "functioning" means here that the item is either in active operation or that it is able to operate if required.

The average availability $A_{av}$ denotes the mean proportion of time the item is functioning. If we have an item that is repaired to an "as good as new" condition every time it fails, the average availability is

$$A_{av} = \frac{MTTF}{MTTF + MTTR} \tag{8}$$

where MTTF (mean time to failure) denotes the mean functioning time of the item, and MTTR (mean time to repair) denotes the mean repair time after a failure. Sometimes MDT (mean downtime) is used instead of MTTR to make it clear that it is the total mean downtime that should be used and not only the mean active repair time.

### 2.6.3 Maintainability

Maintainability is: *The ability of an item, under stated conditions of use, to be retained in, or restored to, a state in which it can perform its required functions, when maintenance is performed under stated conditions and using prescribed procedures and resources* (BS 4778).

Maintainability is a main factor determining the availability of the item. Rijn states that a 25% reduction in time to repair has a much greater influence on availability than a 25% change in the time to failure (Rijn 2007). Rijn also adds that it is also easier to reduce time to repair than to increase time to failure.

One important parameter to measure the maintainability of the machine is Mean Time To Repair (MTTR). MTTR is the mean of all the times it has taken to repair the machine. When maintainability is improved, i.e. repair made easier, MTTR will decrease and as a direct consequence, availability will increase. In addition to MTTR, the first time fix rate of a machine can be used as an indicator of its maintainability.

First time fix rate is simply the percentage of maintenance operations that are solved on the first visit. If more visits are needed this is usually because either the failure was given a false diagnosis or because the technician lacks the necessary tools or skills to perform maintenance. Poor design for maintainability will lead to an increase in MTTR with more false diagnoses and an increased need for special skills and tools that the technician might not have.

## 2.7 Level of detail in reporting

The Offshore Reliability Data (OREDA) project was launched as a joint venture of 8 major oil companies in the early 1980's with the purpose of gaining safety and reliability related data. It then grew to be an extensive reliability data collection project that lasted for nearly 30 years. Sandtorv et al. give recommendations for data collection projects based on their experiences with the OREDA project (Sandtorv et al. 1996). Their recommendation is to “start small and design for flexibility”.

Regarding maintenance reporting in Kalmar one option to consider is to report data at the machine section level (e.g. “engine or “transmission”) and not the sub-section level (e.g. “engine – fuel system” or “transmission – lubrication”). Here the level of detail would suffer, but it would also make data gathering simpler. However this is currently not possible in SAP since a code on the sub-section level is required. If this was made possible it might lead to more failure codes being reported although the level of detail would be reduced.

In 2008 a study was made at Kalmar where the machine section level was used instead of the subsection level (Koivumaa 2008, p.58). This was because the maintenance personnel on occasion had difficulty in determining the correct subsection for the failure and it was then not reported at all.

On the other hand, in some cases it might even be considered useful to define the failure codes at a more detailed level. The three levels are shown in Figure 2.3. As the division is now in two levels – sections and sub-sections – it could be expanded to include sub-sections (Fuel Pump) of sub-sections (Fuel System). However, that kind of decision should not be made too hastily not only because of experiences with the OREDA project, but because of another study.

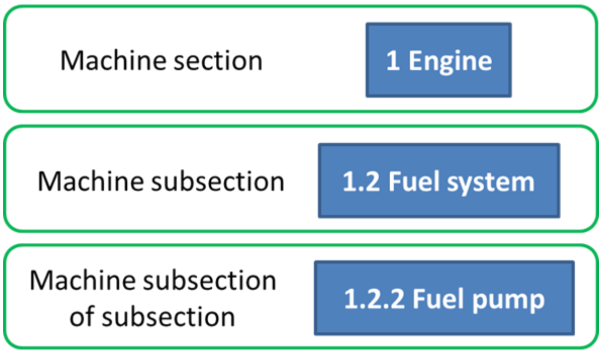



***Figure 2.3.*** *Three levels of data collection.*

A study made by Rijn presents the problem that the more detailed information we wish to gather, the more difficult it will be to gather (Rijn 2007). In Kalmar machines some parts – engines, for example – may change every year with significant mechanical changes to their functioning. Changes are due to legal issues and therefore cannot be avoided. These changes make it difficult to collect data at a detailed level, because they might require changes to the division of sections. This is not desirable since it hurts the idea of having the same division of sections for all instances of the same machine type.

This situation is related to what is called Prater’s principle of optimal sloppiness which Rijn describes (Rijn 2007). The Figure 2.4 from his publication shows there is an optimum level of degree in terms of producing the maximum engineering value. The predictive power of the model will increase up to the optimum level after which an increase in the level of detail results in a decrease of predictive power. Further increase in the level of detail will not lead to more – but to less predictive power.

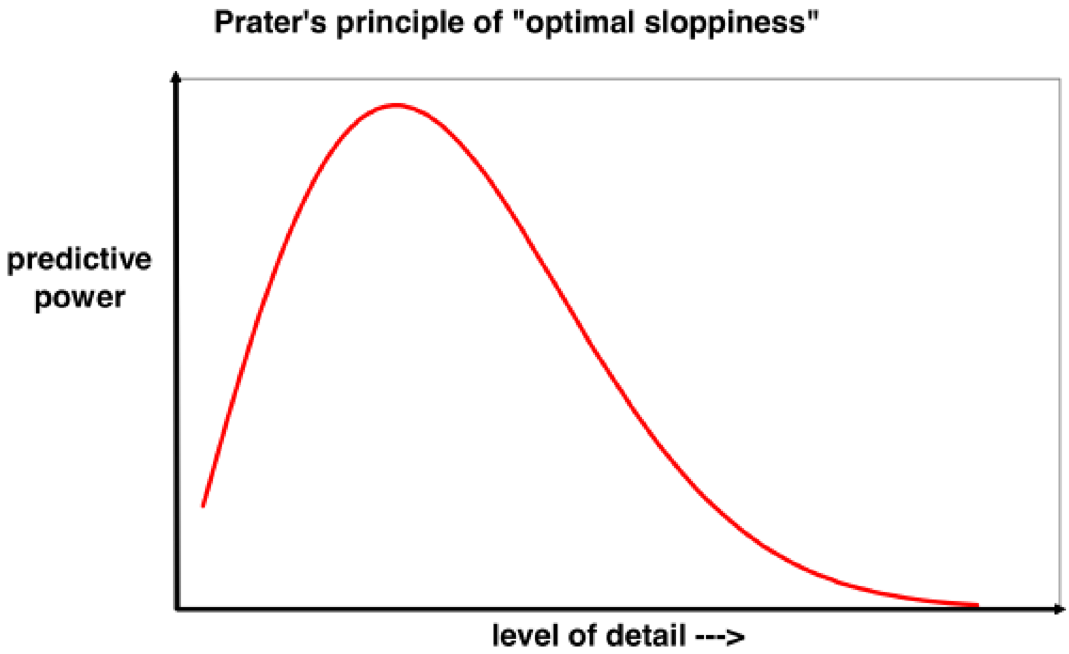



***Figure 2.4*** *Prater's principle of optimal sloppiness (Rijn 2007).*

Rijn explains this decrease in predictive power is brought on by the uncertainty that comes from the additional parameters that the model requires (Rijn 2007). In terms of Kalmar, it is easy to think that for example if our failure distribution models were based on details that go all the way down to the smallest part level, the effort of gathering information to support the model would quickly become overwhelming. This would lead to assumptions being used in models rather than observations and as a result to a decrease in predictive power.

Furthermore, one thing to consider is that Kalmar doesn't manufacture all parts of its machines. There is limited use for information related to for example engines that are manufactured by third parties. Detailed information would give an understanding of what kinds of failures occur in engines, but Kalmar has little possibility of improving their design since it isn't responsible for developing the engines. Kalmar can only give suggestions to the third party manufacturers on where they should focus their development.

Scarf agrees with Rijn and mentions that it is easy to concentrate too much on the invention of new models and put little thought to their applicability (Scarf 1997). Applicability is something that the designers of predictive models should always have in mind. Scarf continues it could be argued that absence of sufficient data in relation to the complexity of the predictive models is the greatest problem related to predictive modelling in maintenance.

Moreover, Scarf states an important view that as the complexity and the number of parameters in the model increases, so does the probability of high correlations between those parameters (Scarf 1997). This makes it difficult to distinguish between equally plausible parameter combinations. Therefore such models are difficult to resolve and have low predictive power. However, while complex models may have low predictive power, the study of them can indicate the scope for simplification.

Regarding qualitative, or subjective data, Scarf claims it is sometimes suspect, because the experts relied on subjective data are often the same experts who are responsible for the current maintenance practice (Scarf 1997). Therefore the suspicion exists that “their expert judgment must surely reflect the current practice rather than the true underlying engineering phenomena”.

In order to avoid the problems with too detailed information gathering, there is a need to find Prater’s level of optimal sloppiness. That means the level that is still useful for the purposes of applying RAM (Reliability, Availability, Maintainability) analysis methods, but not so detailed that it would cause predictive power to drop or that it would overwork the technicians reporting the information.

Since reporting of failure codes is currently neglected in Kalmar, there seems to be little basis for employing an even more detailed level of data gathering. On the other hand, since the SAE J2008 based standard is known to Kalmar technicians, there are grounds for staying in its level of machine sub-sections (Engine – Fuel System) when reporting failure codes. However, since the codes are rarely reported, if the option is possible to add to SAP, it should be considered to make possible to report failure codes on the machine section level.

The machine section level (e.g. Engine, Transmission etc.) surely can not be considered too detailed in that it would work the technicians too hard when reporting maintenance work. On this level, the person reporting has to choose from only 12 different machine sections. It would still leave unanswered the question of whether this level of detail is enough or not.

In the field of offshore wind turbines, Hameed et al suggest that the machine section level would not be enough (Hameed et al. 2011). They state it is essential to know what part inside of a transmission box failed. The failure mechanism is also needed to report and the effect on future failure behavior. While the offshore wind turbine industry differs greatly from the container moving industry, it still gives food for thought about the optimum level of detail.

The next level, the level of machine sub-sections has 97 different codes. This is obviously a lot more than the 12 on the machine section level, but since the technicians aren't required to remember them by heart, this should not be too many. In practice, the technician first chooses the machine section from 12 options and after that chooses the subsection from a maximum of 16 codes. This does not apply to STS codes which do not follow the current standard and are discussed in Appendix A.

It should be noted that analysis done with failure codes by themselves are not enough for example for the pricing of service contracts. To determine the correct price for a service contract, one has to have a good understanding of the contract costs for the machine, e.g. spare parts and labor costs. A good thing about maintenance reporting in Kalmar is that this information of spare parts and labor is available and its importance should not be forgotten.

Therefore, while trying to look for the optimum level of detail in terms of reliability analysis, one should always keep in mind there is other important information that must be reported in the future as well.

## 2.8 Information required for reliability engineering analysis

In order to estimate the reliability, availability and maintainability (RAM) of machines we need as much consistent failure data from the machines as possible. Therefore the need for maintenance data reports in terms of RAM analysis is very high. In addition, the reports have to be gathered into the same database so that RAM analysis can be done effectively. This means that it is preferable to have the whole maintenance history of the machine recorded in the same database. Currently at Kalmar, that database is SAP.

Regarding maintenance history data, Kalmar has different levels of service products ranging from service contracts where all maintenance done on the machine is done by Kalmar to on-call service where the customer buys maintenance from Kalmar only when unable to repair the machine by him/herself. In terms of collecting consistent failure data, it is much easier to collect from machines that are under service contracts where Kalmar technicians are doing all the maintenance work required.

On the other hand, when considering gathering of failure data from on-call service, it has to be noted there is uncertainty over the maintenance history of the machine. This is because with on-call service Kalmar does not know how much maintenance has been done on the machine outside the services it has provided. Therefore the usability of this type of data is not as high though it might still capture some important features of the way the machines fail.

Whether the machine is under service contract or not, in order to effectively estimate RAM parameters at least the information listed in Table 2.2 should be reported on routine basis. The reasons why the listed information is important is explained in chapters 2.8.1 through 2.8.10.

***Table 2.2.*** *Minimum data needed to report for effective RAM analysis.*

| Questions to answer: | Data reported |
|---|---|
| 1. Which machine failed | Serial number and machine type |
| 2. When did the failure occur | Hour counter reading of machine |
| 3. What in the machine failed | Failure Code(s) |
| 4. What was the cause of failure | Cause Code(s) |
| 5. What were the consequences of failure | Failure Effects Code(s) |
| 6. What maintenance activities were done | Activities Done Code(s) |
| 7. How long did it take to repair | Working hours |
| 8. How many technicians were needed | Number of technicians |
| 9. What spare parts were used | List of parts used |
| 10. When was the failure noticed | Date of creation on service notification |
| 11. When was maintenance started | Date of creation on service order |

### 2.8.1 Which machine failed

The combination of a serial number and a material code (i.e. machine type) define individual machines. While in rare cases the same machine can have many different serial numbers in SAP, the combination of a serial number and a material code is unique. This combination defines an equipment code in SAP.

They are important information because without being able to identify machine type, we won't be able to estimate failure distributions for different machine types. On the other hand, if we only track the machine type, we will lose sight of how many operating hours individual machines have and won't be able to manage our maintenance activities accordingly.

### 2.8.2 When did the failure occur

The hour counter reading at time of failure is used to define the age of the equipment. It is also used to calculate Mean Time To Fail (MTTF) and it is important information when determining a failure rate or failure distribution for the equipment.

In addition to failures, some contracted equipment in Kalmar is invoiced based on the number of operating hours. In these cases the hour counter reading is checked regularly even if no fail has occurred.

It should also be noted that if the failure has not stopped the machine from working, the machine may have still been in use after the failure was observed. In this case the hour counter reading is not the same as it was when the failure occurred.

### 2.8.3 What in the machine failed

To further analyze why specific machines fail, the failed components of the machine have to be reported. The more component information is reported the more possibilities to identify critical components of the machine that contribute the most to the unreliability of the machine. This information can then be used in product design to improve reliability. Furthermore, the information is of value also during the operation of the machine.

For example, let’s assume we know a certain component will fail with high probability during the month and will probably harm another component or system. It is then possible to replace that component before further consequences are suffered. This also makes it possible to alert the customers beforehand and ask them when they would like maintenance done instead of suffering the consequences of random failure.

Moreover, to use RAM tools such as Fault Tree Analysis (FTA) described for example by Kumamoto and Henley (Kumamoto & Henley 1996, p.165), large systems (e.g. machines) need to be divided into smaller pieces (components) to be able to analyze system RAM parameters by using component RAM parameters.

### 2.8.4 What was the cause of failure

Cause of failure of components is key information when looking for input to design better components or systems. This is why it should be a routine part of reporting to report if the failure was induced by e.g. wear or breakage.

In the case of third party components, the more information available on cause of failure, the more possibilities for giving feedback to the suppliers. This will enable them to direct their research and development towards improvements that would have more value to Kalmar.

In SAP there is the possibility of recording the cause of failure by cause codes which are shown in Figure 2.5. The current selection of codes includes 7 options including the possibility of describing a cause not found on the list. If used regularly, they could be used to look which types of causes lead to most failures in which components.

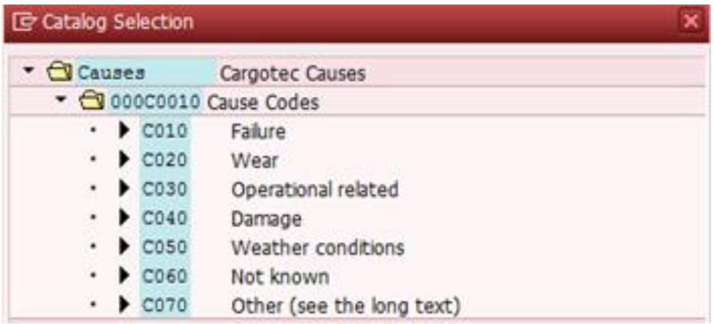



***Figure 2.5.*** *Failure Cause Codes in SAP.*

### 2.8.5 What were the consequences of failure

Some failures hold the machine to a standstill while others allow the machine to be operated before next maintenance. Some failures may induce failures in other parts or systems. Therefore it is important to determine what the consequences of failure were. This consequence of failure is also important information when deciding where to focus development on. It can be also used for prioritizing failures for maintenance.

In SAP there is a possibility of defining the consequence of a failure on machine level by a specific Failure Effects code as shown in Figure 2.6. The failure effects are divided into 4 categories: machine halted, machine out of operation, machine able to run, but maintenance required and machine able to run, but safety compromised.

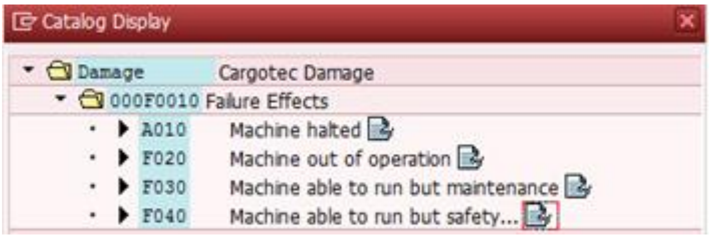



***Figure 2.6.*** *Failure Effects codes in SAP.*

### 2.8.6 What maintenance activities were done

It is not simply enough to state that the problem was fixed, but also how was it fixed. What type of maintenance activities were taken and how have they changed the failure behavior of the machine or machine sub-section.

For the reporting of activities done, in SAP there is a code list labeled Activities Done which is shown in Figure 2.7. The list contains the possible activities done on the machine to repair the failure and the possibility of using a long text description to describe activities not found on the list.

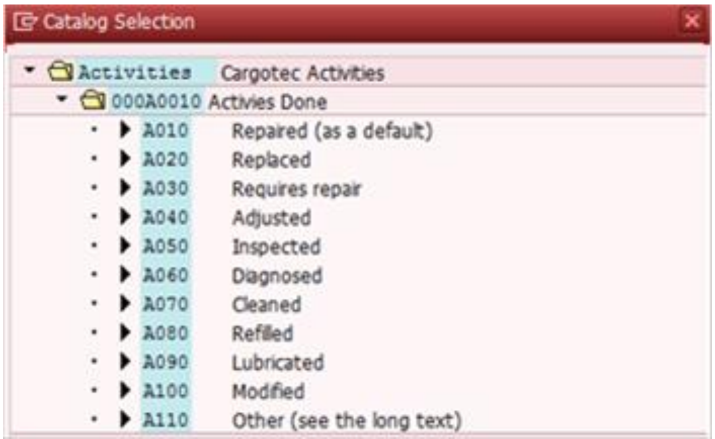



***Figure 2.7.*** *Maintenance Activities Done codes in SAP.*

### 2.8.7 How long did it take to repair

The time to repair is used to calculate Mean Time To Repair (MTTR), which is a necessary parameter for calculating the availability of equipment. MTTR is also an indicator of the maintainability of the machine and it's used when evaluating the availability of maintenance (i.e. the probability that technicians are able to provide maintenance when required).

### 2.8.8 How many technicians were needed

Amount of technicians needed is important information when making estimates on how many technicians are needed to have standing by in case of failures. If we know how many technicians are needed for each task and how often those tasks occur, we will be able to quantify the service level of the workshop in terms of technicians available, i.e. the probability that there will be enough technicians to provide maintenance.

### 2.8.9 What spare parts were used if at all

Information about parts needed to complete maintenance work is important when evaluating the consumption of parts. Furthermore, the information allows the estimation of inventory levels for spare parts. The better understanding about the consumption of parts, the easier it is to manage inventory.

Also, the better the prediction of consumption of spare parts, the more Maintenance Delay Time (MDT) will decrease, because technicians will spend less time waiting for the parts to arrive. As the amount and price of spare parts vary with different machines, prioritizing is also needed here. Priority of parts should be determined based on availability and price.

When discussing spare part consumption, it would be specifically important to get a hold of major component costs. These are the components that have the highest lifetime costs for machines. Spare part costs directly contribute to the machine cost per hour which is a key factor when calculating service contract costs.

As an example, the maintenance of rims and tires is often left out of maintenance contracts due to the unpredictability of their maintenance cost. For example for Straddle Carriers the cost of rims and tires per hour is approximately 5€ per hour, but is considered difficult to evaluate on a case by case basis for the calculation of service contracts. For this reason, it would be valuable to be able to easily separate the cost of rims and tires from calculations of material costs per hour.

### 2.8.10 When was the failure noticed and maintenance started

While the operating hours of machines are a good indicator of equipment age, they can't be used to quantify Mean Maintenance Delay Time (MMDT) – the time it takes from observing the failure to starting maintenance. To be able to quantify MMDT, we need information on the calendar time when the failure occurred and when repair was started. The time between is the Maintenance Delay Time (MDT) and their mean is the MMDT.

When reporting to SAP, calendar time of failure occurrence can be considered to be the service notification creation date. Similarly, maintenance can be considered started on the creation date and time of the service work order. This way, MDT is the time between the creation of service notification and the creation of service work order. However, this is not possible, if they are created after the work has been done which is sometimes the case in Kalmar.

## 2.9 Reliability engineering in new product development process

According to Østerås et al. the New Product Development (NPD) process is driven by three factors which are technology, market and management (Østerås et al. 2005, p.26). As an example, development of a container moving vehicle may be driven by advances in sensor technology or by competitors who have better performing machines or by management, to increase market share.

Østerås et al. state that reliability engineering is needed in every step of the NPD process to make sure the desired performance is met within the given boundaries of development (Østerås et al. 2005). These boundaries are related to business level objectives, major functions and operation of the product, spatial and structural relationships of principal components and to the processes for economic and high quality production.

Østerås et al. also address the importance of maintainability and state the 5 typical questions to ask during an NPD process to address maintainability considerations (Østerås et al. 2005, p.63). Answers to these questions determine which parts have high failure rates, how can these failures be diagnosed easily, how quickly can the system be repaired, how much downtime is acceptable and what kind of preventive maintenance needs to be performed.

Moreover, In Figure 2.8 Østerås et al. show the link between customer dissatisfaction and time of failure (Østerås et al. 2005, p.65). As time under warranty passes, the level of dissatisfaction resulting from product failure decreases. However, if the product fails immediately after warranty is over, the customer may be even more disappointed than if the product had failed at the very beginning. However, again if the product does not fail and time passes on, the customer's level of disappointment at moment of failure is decreased.

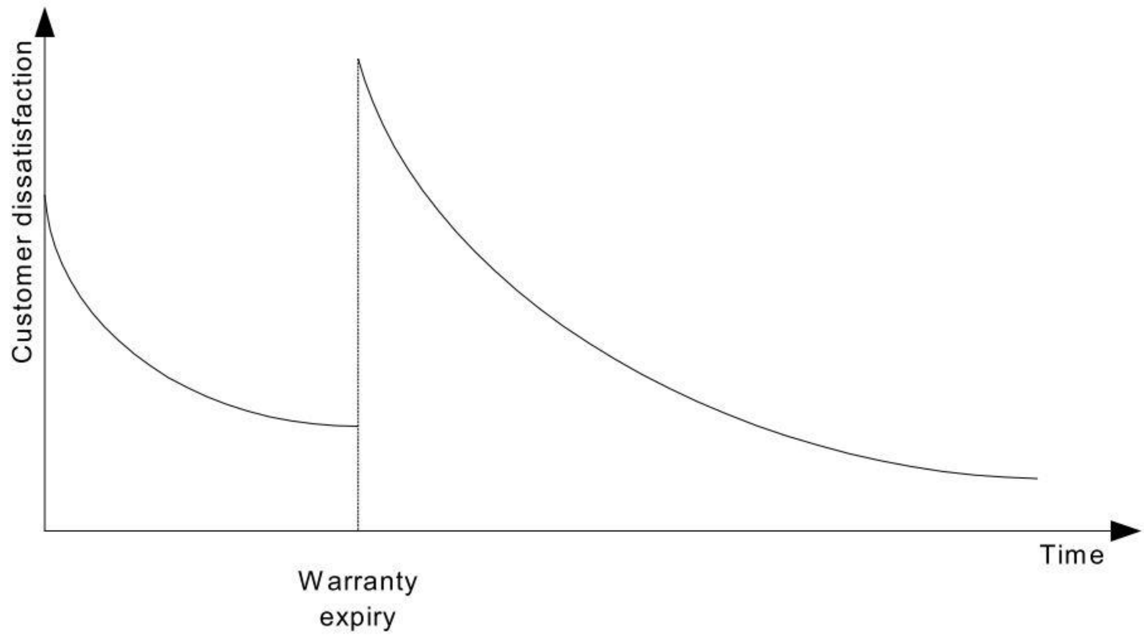



***Figure 2.8.*** *Customer dissatisfaction as a function of time during and after warranty (Østerås et al. 2005, p.65).*

As Østerås et al. state, one of the problems that reliability creates in the NPD process is that it varies over the product lifecycle (Østerås et al. 2005, p.75). A typical case is shown in Figure 2.9 where reliability increases throughout the design phases as potential failure causes are removed or limited. Once the item is put into use, its reliability deteriorates with age due to factors such as environment, operating conditions and maintenance.

This rate of deterioration can be controlled through preventive maintenance whose effectiveness decreases while maintenance costs increase as the item ages. This will eventually lead to the item being discarded and replaced by a new one (Østerås et al. 2005, p.76).

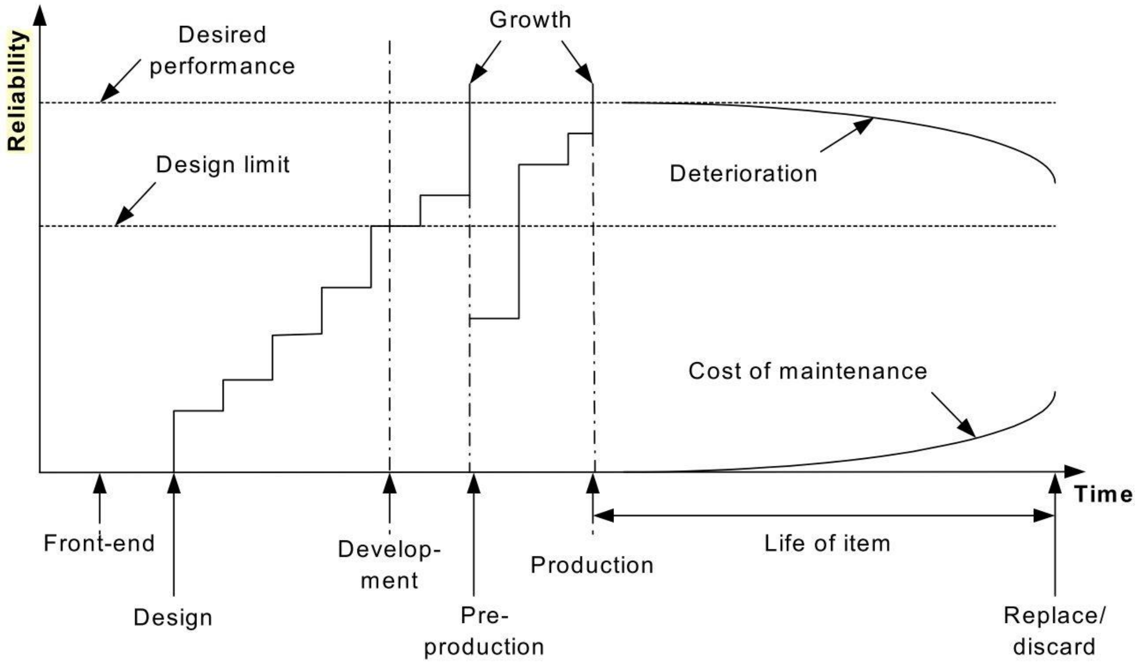



***Figure 2.9.*** *Variation of reliability during product lifetime (Østerås et al. 2005, p.67).*

Figure 2.10 shows how Murthy et al. regard the role of reliability engineering in new product development (Murthy et al. 2009). They state reliability decision-making involves two tasks the first of which is defining the reliability requirements at system level (e.g. a certain level of reliability or availability). The second task is then to derive the reliability specification at component level. This allocation of reliability specification to components can be done in many ways. One such way is presented by Virtanen and Hagmark (Virtanen & Hagmark 2001).

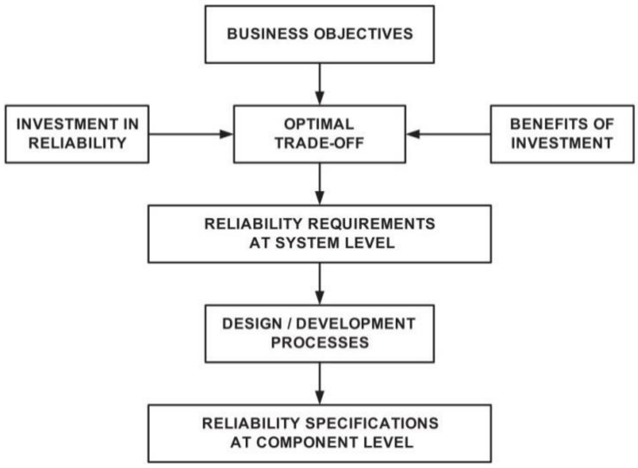



***Figure 2.10.*** *Reliability engineering in new product development (Murthy et al. 2009).*

Barnard describes the design process as an iterative process where reliability engineering is used to verify the design to see if it meets reliability requirements (R.W.A. Barnard 2008). The process described by Barnard is shown in Figure 2.11. He further states that once production has started reliability activities change from proactive to reactive and reliability can only be developed as high as the inherent reliability of the product or system.

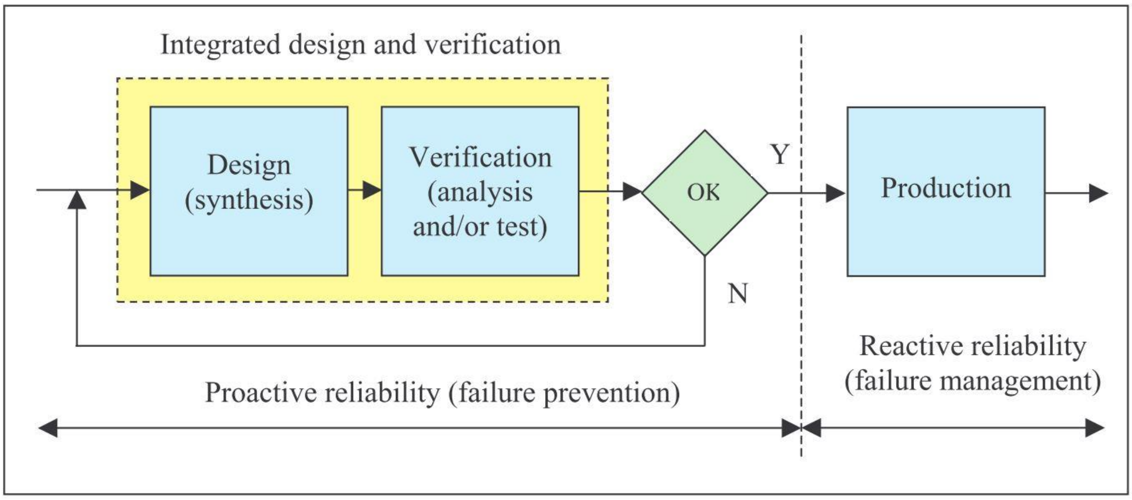



***Figure 2.11.*** *Product design process (R.W.A. Barnard 2008).*

# 3. CASE EXAMPLE: VUOSAARI WORKSHOP

As the service technicians are responsible for maintaining the machines they are key individuals for information gathering. They are also often in direct contact with customers of Kalmar and their performance will have a direct impact on how the customers experience the quality of the maintenance service.

While there is clear motivation to keep the technicians busy repairing, effort must be put into decreasing the amount of time it takes for them to execute other tasks, such as reporting. As part of the study of the current situation at Kalmar, a visit was made to the workshop at Vuosaari harbor, Helsinki Finland. The manager was interviewed and also observed as he demonstrated the input of maintenance data into SAP.

According to the manager at Vuosaari workshop, before SAP, they spent about 3 days per month to report maintenance work. After adopting SAP, they now write reports twice per week which amounts to 8 or 9 days for reporting per month with an increase of 40 hours on time spent reporting. That is an increase of 200% in time spent on reporting. At the same time there has been a 25% increase in the amount of maintenance work done which explains only a fraction of the increased reporting time.

Therefore there is a clear need to study the data reporting process and to simplify it and make it easier wherever possible to reduce the time it currently takes. The time gained from a faster and easier reporting process will enable technicians and managers to spend more time doing actual maintenance work or it can be spent for example on training. As described in Chapter 2, motivation for the simplification of the data reporting process can be found from the viewpoint of employee retention.

The time saved on reporting and spent on serving the customer increases the technicians' ability to meet customer needs. This in turn increases employee satisfaction and leads to employee retention which in turn leads to a higher quality service. Turning this around, dissatisfaction of employees will result in a higher employee turnover rate which in turn will lower the service quality.

The Vuosaari workshop clearly expressed their dissatisfaction with the current reporting tool which is a clear signal to conduct a study on the maintenance reporting process. Based on information gained at the Vuosaari workshop and Kalmar manuals for SAP reporting, a flowchart was created showing the current process of maintenance reporting in SAP.

In Chapter 3.1 the Vuosaari workshop is presented. Chapter 3.2 describes the process of reporting maintenance data and Chapter 3.3 lists the information currently reported. In Chapter 3.4 the current list of information is compared to the list in Chapter 2.8 with the required information for RAM analysis.

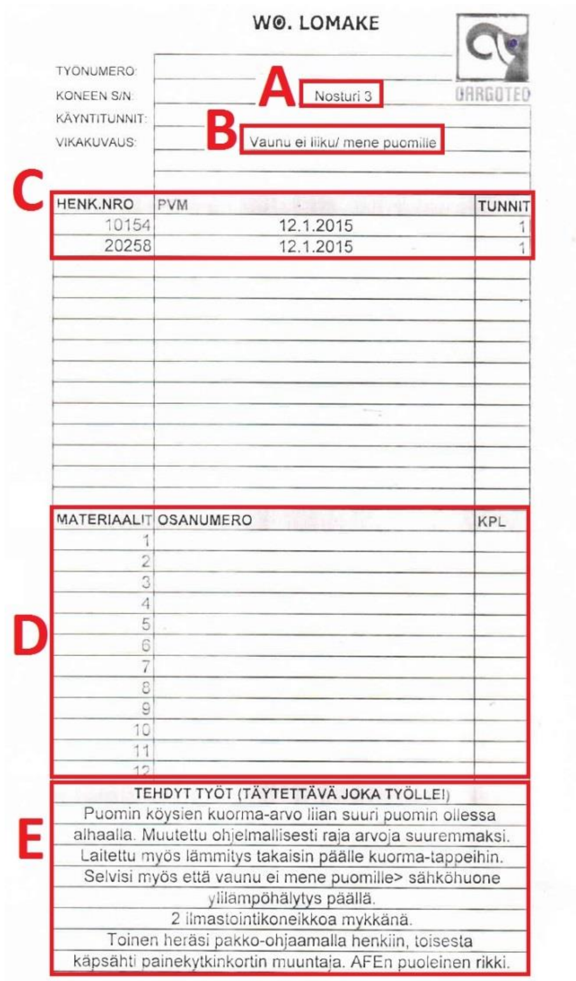
## 3.1 Overview of Vuosaari workshop

The workshop is located in Helsinki Finland, at the Vuosaari harbor. It started its operation in early 2009. They have 8 technicians of which 7 work at the workshop and one travels to customer sites around southern Finland. The Vuosaari workshop has currently only straddle and shuttle carriers on maintenance contracts. They make up 75-85% of their workload while the rest comes from on-call service from various types of machines.

In addition to corrective maintenance, maintenance work at the workshop includes preventive maintenance tasks that are initiated according to the service manual at specific hour counter reading values. Vuosaari workshop’s work also includes tasks such as moving equipment from one point to another and adding new functionality to old equipment.

## 3.2 Process of reporting maintenance data

Technicians do not input information directly into SAP. Instead they use forms such as shown in Figure 3.1 where they mark the information required. While in this example the work report is done on computer, it is also common practice to write with pen on paper. The information is then transferred to SAP by one of the two people responsible for maintenance reporting in SAP.



WO. LOMAKE

TYÖNUMERO:
KONEEN S/N: A Nosturi 3
KÄYNTITUNNIT:
VIKAKUVAUS: B Vaunu ei liiku/ mene puomille

C

| HENK.NRO | PVM | TUNNIT |
|---|---|---|
| 10154 | 12.1.2015 | 1 |
| 20258 | 12.1.2015 | 1 |

D

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E

TEHDYT TYÖT (TÄYTETTÄVÄ JOKA TYÖLLE!)
Puomin köysien kuorma-arvo liian suuri puomin ollessa alhaalla. Muutettu ohjelmallisesti raja arvoja suuremmaksi. Laitettu myös lämmitys takaisin päälle kuorma-tappeihin. Selvisi myös että vaunu ei mene puomille> sähköhuone ylilampöhälytys päällä.
2 ilmastointikoneikkoa mykkänä.
Toinen heräsi pakko-ohjaamalla henkiin, toisesta käpsähti painekytkinkortin muuntaja. AFEn puoleinen rikki.

***Figure 3.1.*** *A typical work report from Vuosaari workshop, written in Finnish.*

In the work report form shown in Figure 3.1, the area marked as A includes the name of the machine (“Nosturi 3”) which is a name familiar to the workers at Vuosaari workshop. In B is a short description of the failure in Finnish. Marked in section C are from left to right: person number, date of work done and working hours. Section D is reserved for spare parts while section E contains a written description of the work done.

As the form and report are in Finnish, it is very difficult for anyone other than a Finnish speaking analyst to extract necessary information from it. Furthermore, the use of workshop specific names for the machines (such as “Nosturi 3”) will make it impossible for anyone outside the workshop to understand which machine it exactly is. Therefore it also must be someone within the workshop who does the reporting into SAP.

Currently the persons reporting are in the same workshop and reports such as this one are given as information to them. They need to translate the information into a form that SAP will accept as a report. This leaves room for error in translating the information into SAP from the paper written report.

It should be noted that in addition to the information listed above, the work report form also has spaces for the service order number and machine operating hours, but these are left blank in this case. As mentioned earlier, technicians don't report their own work into SAP. Instead, after completing the form, the technician hands it to one of the people responsible for SAP reporting.

This is because it has been seen impossible to employ all the workers directly with SAP reporting. One reason for this is that Kalmar has to pay a monthly fee for each SAP user. Another reason is that the technicians come from various backgrounds and have different levels of computer knowledge. Management in Vuosaari believes that if each technician was required to report their own work into SAP, it would take too much of their time. Also there is a doubt if the workers can be trusted to accurately mark down their own working hours.

Because reporting is done by only two people, it puts a time pressure on them. The time they spend typing everything into SAP is time directly away from their other duties. This has led to a practice where instead of opening a new service notification for each failure, one notification is opened per machine per month. Then all maintenance work done on that machine during that month is written under the same service notification.

This method of reporting decreases the time it takes to report maintenance work into SAP and while the workshop recognizes it is not the ideal way if reporting, it fits their needs. They say that because reporting of work takes so much time, they do not have the resources for more detailed reporting.

In addition to reporting maintenance data into SAP, the workshop is also sometimes required to check customer reference data (e.g. if the machine has been sold forwards) and change them if necessary.

## 3.3 Maintenance data entered into SAP

Currently, invoicing sets the bar on what information technicians are expected to report. This is information that if it doesn't exist, the higher steps of the organization will come asking for it from the technician, because they can't invoice without it. Therefore, as it is monitored from a higher level, the technician can be sure he is reporting important information. This is not the case with failure data information, which can be omitted from the report without it raising questions from higher levels of the organization.

The information that the Vuosaari workshop is required to report into SAP is listed in Table 3.1. The different information is explained in more detail in chapters 3.3.1 – 3.3.8.

***Table 3.1.*** *Data required to report by the Vuosaari workshop.*

| Data required to report |
|---|
| 1. Machine identification |
| 2. Description of work in open text |
| 3. PO number or customer reference |
| 4. Number of technicians |
| 5. Working hours |
| 6. Travel and hotel expenses |
| 7. Amount, type and price of spare parts |
| 8. Cost center |
| 9. Hour counter reading (recommended) |

### 3.3.1 Serial number of machine

The serial number or other identification of the machine is required in order to determine which machine was repaired.

### 3.3.2 Written description of work

For the customer, it is important to have a clear description of maintenance work done on their equipment. This description is written down in SAP to an open text field from where it is easy to extract for the customer to see. The length and level of detail needed varies from customer to customer, but as far as invoicing goes, this description is considered important information by Kalmar service management.

In data analysis, the description text is sometimes used to interpret otherwise confusing work reports. For example, in the absence of hour counter readings or spare parts used, the analyst can look at the written text to try and find the information there. On the other hand, if spare parts are listed, the progression of work can remain unclear if it is not explained. So in data analysis it functions as support to the otherwise reported work, but is not a sufficient basis for data analysis by itself.

If the customer would accept failure, cause, effects and activity codes as a report, it would be possible to ignore writing an open text description of work. This would reduce the time needed for reporting and would therefore also ease the workshop’s workload.

### 3.3.3 Purchase order number or customer reference

For invoicing purposes, there is an obvious need to identify who to invoice. This is reported by a purchase order number or other customer reference like the name of the company or a contact person within the company.

### 3.3.4 Number and working hours of persons

As the technicians are paid according to the hours they work, this is information they willingly report. This is information that can be used when estimating MTTR and also the amount of workers needed at a workshop on specific times to reach a certain availability for maintenance work. It should be noted that there are cases where the reporting of work is not accurate enough to use working hours as a basis for MTTR calculation. For example, all working hours may be written down for one machine even though there was maintenance done on several.

### 3.3.5 Travel and hotel expenses and daily allowances

This information is needed from the technicians so they get the right amount of compensation. As with working hours, these are routinely reported.

### 3.3.6 Amount and price of spare parts

Technicians must report the spare parts they use so they are taken account for in calculating costs for the maintenance work. When low cost parts are in question, they are not always reported, because some workshops have what is called unaccounted stock or grab inventory. For example in Belgium, bolts up to M12 are grab inventory that do not need to be reported when taken.

Another reason for not reporting spare parts is because it takes time and resources to report them. It is reported that in some workshops for example, if the maintenance of a machine only requires a 3€ part it is not reported. Instead the part is simply taken off the shelf, installed into the machine and the missing part is accounted for in the next inventory where it is just marked as loss.

### 3.3.7 Cost center

All costs incurred are divided among cost centers so it is possible to keep track of where all the different costs are coming from. This is information not needed by the technicians, but if they don’t report it, they will hear about it from higher organization levels.

### 3.3.8 Hour counter readings

Hour counter readings are not mandatory, but only recommended. Therefore they are not reported on a routine basis. Furthermore, when they are reported, they are often reported in open text fields instead of using the Create Measuring Document –module that is speficifally meant for keeping track of hour counter readings.

## 3.4 Current vs needed for RAM

Comparison between the current list of reported information to the information needed for RAM analysis listed in Chapter 2.8 is done in Table 3.2. It is seen that the information missing are the ones that would locate the failure to a specific section or subsection (Failure Code), the cause and consequence codes of the failure and the activity undertaken to repair the failure (Activity Code). Also the hour counter readings aren't reported in the proper SAP module, if reported at all and the time of creation for the service notification and order are the same since work is reported to SAP from start to finish in one sitting.

The missing codes and the recording of hour counter readings to open text fields is something that should be changed if feasible RAM analysis is pursued, because the time of failure is critical information for the analysis. Without easy access to the information of what failed when with what consequences and how it was repaired by how many people in what time, it will be very slow to evaluate RAM parameters since work reports have to be examined one at a time.

***Table 3.2.*** *Data currently required to report by the Vuosaari workshop (items 1 through 9) and the data required for extensive RAM analysis as defined in Chapter 2.8 (items 10 through 15).*

| Data reported |
|---|
| 1. Machine identification |
| 2. Hour counter reading (recommended) |
| 3. PO number or customer reference |
| 4. Description of work in open text |
| 5. Cost center |
| 6. Travel and hotel expenses |
| 7. Working hours |
| 8. Number of technicians |
| 9. Amount, type and price of spare parts |
| 10. Failure Code(s) |
| 11. Cause Code(s) |
| 12. Failure Effects Code(s) |
| 13. Activities Done Code(s) |
| 14. Date of creation on service notification |
| 15. Date of creation on service order |

# 4. STUDY OF THE MAINTENANCE DATA COLLECTION PROCESS

To get an idea of the level of difficulty in maintenance data reporting, the service manager at Vuosaari workshop was asked to give a demonstration on how to report the information into SAP. It was apparent from observing the demonstration that the process was over-complicated as also mentioned by the manager. Therefore further research was done on the SAP training manuals provided to Kalmar employees.

In Chapter 4.1 the process of reporting maintenance data is described while the consequences of the extensively laborious process are listed under Chapter 4.2.

## 4.1 Process of reporting data

In the SAP training manuals data reporting is divided into modules which instruct how to report specific information (e.g. hour counter reading, man hours etc.). Each module begins with the user entering a transaction code with letters and/or numbers. Then different amounts of inputs are required, depending on the module in question. After all inputs have been given, the information assigned to the module has been reported.

Regarding data reported into SAP, the current modules used by the Vuosaari workshop are shown in Figure 4.1. The figure also shows the two modules not used that if they also were used, they would give useful, easily accessible information for RAM analysis. While some of the deficiencies in reporting might be attributed to reasons such as lack of training and motivation on part of the technicians, most of the fault is in the reporting system as will be shown.

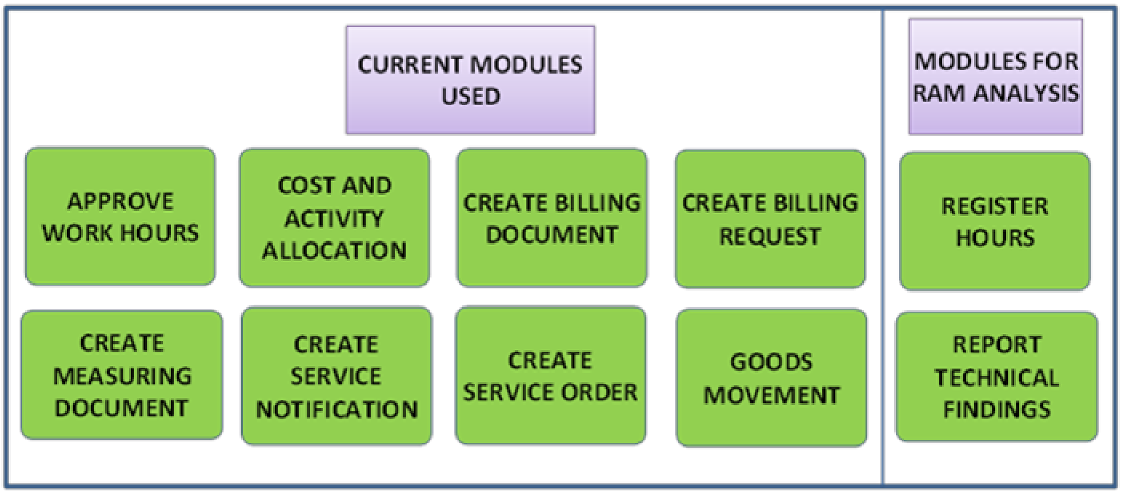


***Figure 4.1.*** *Current SAP modules used by Vuosaari workshop.*

In addition to using the work reporting demonstration and manuals for source material, the workshop at Vuosaari harbor was queried by email to find answers to questions not apparent from the manuals, such as the actual transactions they use when reporting work. Based on the information two flowcharts were created from the process: a general view (Figure 4.2) with labeled modules and a detailed view (Figure C.1 in Appendix C) that shows the modules in greater detail.

Since the current process of maintenance data reporting does not include two important modules in terms of RAM analysis, they are shown under the charts as a reminder that they too should be included in the process. These two modules are the Report Technical Findings module (RTF) and the Create Measuring Document module (CMD).

The RTF module includes information about the failure. By completing the module the user will have reported the failure code that describes which part or parts had failed and the consequence of that failure. Also what is recorded is the maintenance activity done to repair the item. The data is input and stored under the “analysis” tab in the service notification. The CMD module is where the technician is supposed to write down the hour counter reading on the machine. Both modules contain important information that is currently not reported.

The reporting of maintenance information to SAP follows the blue arrows in the flowchart. The process begins with Create Service Notification module and then continues to Create Service Order. Once all modules are completed, the maintenance reporting is completed for the work in question.

In addition to the visual image the flowcharts provide, the amount of inputs and screens and tabs were calculated. Their amount has a direct influence on the cognitive load exerted on maintenance workers. The amount of inputs and screens and tabs does not only reflect the time it takes to report maintenance work, it is a reflection of the actual mental exertion that the workers are put through when they are reporting information.

Currently, the process consists of 8 modules that require at least 100 inputs on 35 different screens to complete. The inputs needed to complete individual modules vary from 4 to 27. Here an input means information added or command executed by mouse or by keyboard. As can be seen from the two modules currently not included, the RTF and CMD, they add at least 22 inputs and 11 screens or tabs more to the reporting workload.

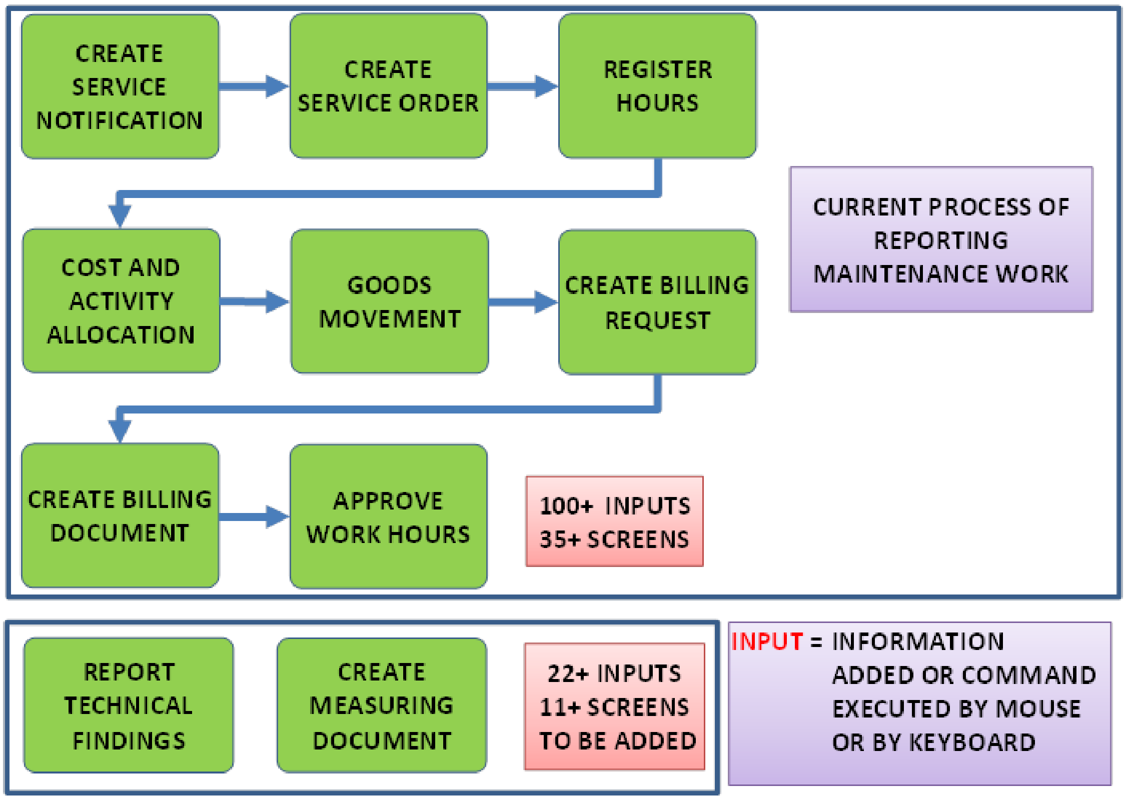


***Figure 4.2.*** *General view of the current process of maintenance data reporting.*

In the detailed chart, shown in appendix C, each module is expanded to include all the steps required to finish that module. Contents of the modules are presented in detail in figures C.2 – C.11 in appendix C. As can be observed from there, a single module is not that complicated and can be finished by following shown steps. Therefore the issue isn't with individual modules.

Instead, the issue is with the combination of the 8 or 10 different modules. The complexity of reporting is greatly increased when all of the 8 modules need to be completed by the same person. In some countries, for example in England, there are different people responsible for different parts of the reporting process. Even if single modules are more complicated then needed, it is much easier to handle a selection of few modules than to try and manage the whole process by yourself.

The flowchart is not 100% accurate when compared with the actual reporting process at Vuosaari workshop. This is because some modules can be completed parallel to each other as mentioned earlier. Therefore it is not always necessary to complete a module before starting the next one. One example of this is the service order creation module through its unique transaction IW31 or through the Change Service Notification module by clicking the appropriate link.

Also work status changes (e.g. “planned” to “work done”) can not be seen from the chart as they can be done in different stages. In practice this means that the process of data reporting is not a completely straight line of modules in series as shown on the flowchart, but rather some of them are in parallel and you also have to change the work status to complete the process.

As it is, the process in the real world is better in some parts (parallel vs. series) than the one depicted in the flowchart, but also worse in other parts (changing work status). While the individual modules can be completed by anyone by meticulously adhering to the instruction on manuals, it is easy to see by looking at the flowchart why information reporting is considered to take too much time and effort in SAP. The problem of reporting taking too much time also creates other problems related to data reporting.

## 4.2 Bad practices in maintenance reporting

Technicians should be busy repairing; they should not be busy reporting too. The larger the workload they have the more they will try to find ways of cutting corners to meet their maintenance and invoicing deadlines.

As a direct consequence of the time and effort consuming way reporting is done, Kalmar is losing much of the valuable information that could be used for reliability analysis if the information was reported to SAP as intended. In this section the different quality deficiencies in maintenance reporting are explored.

### 4.2.1 Not reporting the information

As the information needed for reliability analysis is not needed for the maintenance workers themselves, they may choose not to report the information at all. This is often the case with hour counter readings and with failure codes. In total, hour counter readings are marked on 22.5% of all service notifications (data up to December 2014) when in fact this should be a routine reporting task with a percentage close to 100%.

Major contributors to the low percentage of hour counters reported are the tedious steps required to record the data into the Create Measurement Document –module in SAP. While routine information should be easy to input to the system, to report hour counters, one must open up a separate transaction screen from where he/she can access the measurement document. This combined with all the other tedious steps in using SAP and with the fact that the hour counter reading is allowed to be left out of the report by higher levels of organization leads to low reporting levels.

Failure codes on the other hand, can be found roughly in 1 on every 6 reports (17.2%), meaning there aren't many reports that designate the location of the failures in Kalmar machines. It is possible to get some of the missing information from spare parts used, but not maintenance work where the failed part has been repaired and put straight back to use. Without the information on where the failure has occurred, we are left with a very general view of the way machines fail.

### 4.2.2 Reporting data only in open text fields

One form of data loss is the reporting of data in open text fields. The information is stored in the system, but it is very difficult to extract for further analysis. For example, in some countries, such as Finland, Germany and the Netherlands, technicians routinely use open text fields in SAP to report hour counter readings instead of using the Create Measuring Document –module.

As stated in Chapter 3.3.1, some open text information is essential, because it is demanded by the customer. However, if the information is only recorded in open text fields, it is very time-consuming to use it in maintenance analysis tasks, because SAP search routines don't allow searches based on the content of open text fields.

While it is a good thing that the workers are recording the information even in open text fields only, the information has limited use if not reported correctly. This means that in order to use the information, the analyst has to manually open every service notification he wants information on and then manually transfer the information to another program for further analysis. This is not feasible for extensive analysis.

However, open text information can sometimes be of help, if the other data is unclear as explained in Chapter 3.3.2. Failure codes and spare parts can't capture all of the maintenance data available and sometimes the open text field acts as an explanatory text that helps better understand the work done.

If data were reported in the right manner, SAP has several search functions that allow the extraction of data and then to transfer it to some other program (Excel for example) for further analysis.

As a direct consequence of the difficulty of extracting information from open text fields, the analysis is done with a practice where two hour counter readings are used to represent the entire population. The first reading is taken from a notification with an early date and then the last reading from the latest notification with an hour counter reading.

This is done in order to get the time frame in which all failures have occurred. Then all failures are evenly divided into that frame. This gives an approximation of when failures have occurred, but the approximation carries the assumption of a constant hazard rate (e.g. exponential distribution) which means that the age of the machine has no effect on its reliability. To be forced to make assumptions such as this is not desired in analysis and they are also usually incorrect. This is because exponential failure distributions are not accurate for most machines.

One more thing to note about the use of open text fields in reporting is that they provide no set structure for the reports. Each technician writing reports into open text fields has their own style and order of describing the work. This increases the difficulty of browsing through the open text work descriptions.

### 4.2.3 Reporting in different languages

Furthermore, the reporting of data into open text fields carries another problem – that of language. Workers in Finland report in Finnish, while in France they report in French as shown in Figure 4.3. Unless the analyst is familiar with the language, he/she will have a hard time going through all the information while attempting to cross the language barrier. This problem is not completely covered by translation software as technicians often write in dialect or use abbreviations that are well known to native speakers, but unknown to translators – human or software.

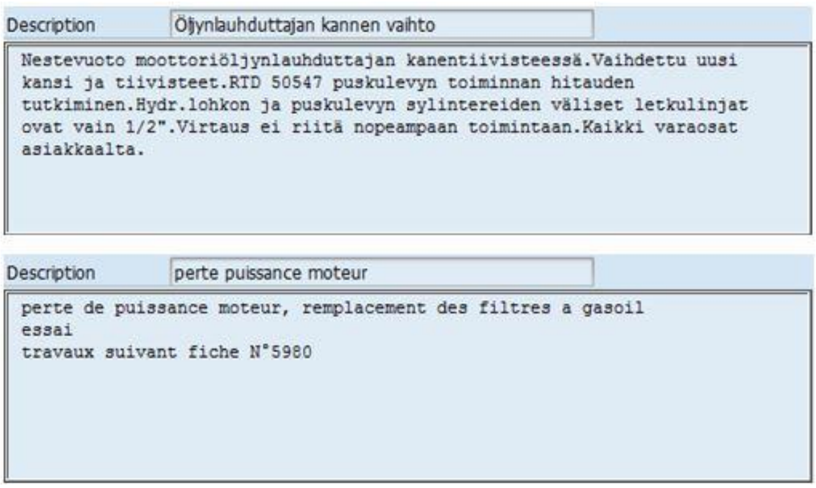


***Figure 4.3.*** *Two open text work descriptions in SAP in Additional data –tab in Service Notification. Descriptions in Finnish (above) and in French (below).*

Moreover, as observed from the work report shown in Figure 3.1 in Chapter 3, technicians sometimes use terms familiar only to a small group of people. Such terms are for example names for the different machines that everyone inside the workshop knows, but no one outside does (e.g. “Nosturi 3” in Figure 3.1).

### 4.2.4 Reporting one service order per machine per month

Another outcome of the difficulty of data reporting is the adoption of a policy in which technicians in countries such as Finland and the Netherlands open one work order per month per machine. All maintenance work done on the machine during that month is recorded to the same open text field. This policy hides the amount of maintenance operations done on machines as – again – the information is difficult to extract from the open text fields. Moreover, this policy increases the delay between maintenance work done and reported and therefore also increases invoice lead time.

# 5. IMPROVING THE DATA REPORTING PROCESS

Based on the study of the maintenance data collection process presented in Chapter 4, there is a need to improve the current process of collecting data. In this chapter we look at the different ways how to help the data collection process in SAP. Chapter 5.1 looks at improvement through transaction layout redesign. Chapter 5.2 looks at mobile service tools for reporting while Chapter 5.3 discusses increasing automation in data reporting. Chapter 5.4 looks at defining catalog profiles according to machine type. Chapter 5.5 examines the idea of improving the structure of work reports while in Chapter 5.6 the approach of hiring more staff is discussed.

## 5.1 Transaction layout redesign

Because time and money are always scarce, the development path of least time and money needed was explored first. On this path there is no effort to reduce the amount of SAP modules needed, but instead, the transaction layouts are redesigned.

SAP offers ready tools for layout design which are already available to Kalmar with no added cost. Regarding the other precious resource, time, the changes made to the layouts are quick to do and can be customized on planning plant level. This is a huge upside since different countries have different reporting processes with different amounts of people involved.

What the redesign means in practice is that SAP layouts have what are called blocks where all the different text and information fields are. Figure 5.1 shows an example of a block named “Reference object”. There are 4 different fields inside the block: Equipment, Serial number, Material and Device data. Equipment and Material fields also have explanatory texts that help identify the machine.

Inside these blocks, it is possible to hide or show individual fields, but the actual size of the block always remains the same. What this means is that if the Device Data field is hidden from the block shown in Figure 5.1, it will not change the size of the block but will instead just show a blank space where Device Data used to be.

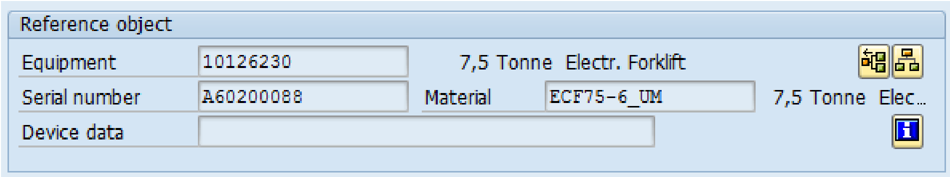


***Figure 5.1.** "Reference object" block in SAP.*

So while the layout can be changed by making changes inside the blocks, the blocks themselves are the same size as always. However, it is also possible to reorganize the layout by moving the blocks themselves to new positions either on the same screen or by placing them behind tabs. New tabs can be created or old ones hidden.

This capability can be used to bring the most often needed blocks to the forefront so they can be immediately seen once the transaction is started. This will reduce the amount of screens needed and will also reduce time needed to search for the important information fields currently located in the middle of unnecessary information such as in Create Service Order screen shown in Figure 5.4 in Chapter 5.1.2.

However, as was first stated, the amount of modules needed does not decrease with this approach and even the amount of screens stays high, because many of the screens are tied to the transactions themselves and cannot be removed. Therefore the user would still need transaction codes and inputs to jump from one screen to another. Despite these doubts about the efficacy of the layout redesign approach, it was explored.

It was found that in many transactions there was no significant improvement to be achieved by using this method. Such transactions are KB15N (Cost allocation), KB21N (Activity allocation), MIGO (Goods movement), DP90 (Create Billing Request), VF01 (Create Billing Document), CAT2 (Register hours), CATS_APPR_LITE (Approve Work Hours) and IK11 (Create Measuring Document).

Layouts where some improvement could be achieved by changing the layouts are briefly discussed next.

### 5.1.1 IW51, Create Service Notification

Figure 5.2 shows the current layout of the Create Service Notification transaction. The Service Notification is used to notify that a machine needs service. In the Service Notification, the machine is identified either by its equipment number or by the combination of machine type and serial number. In addition to identifying the machine, the failure is described by a short, open text description. Also the person creating the notification and the Purchase Order number are written down.

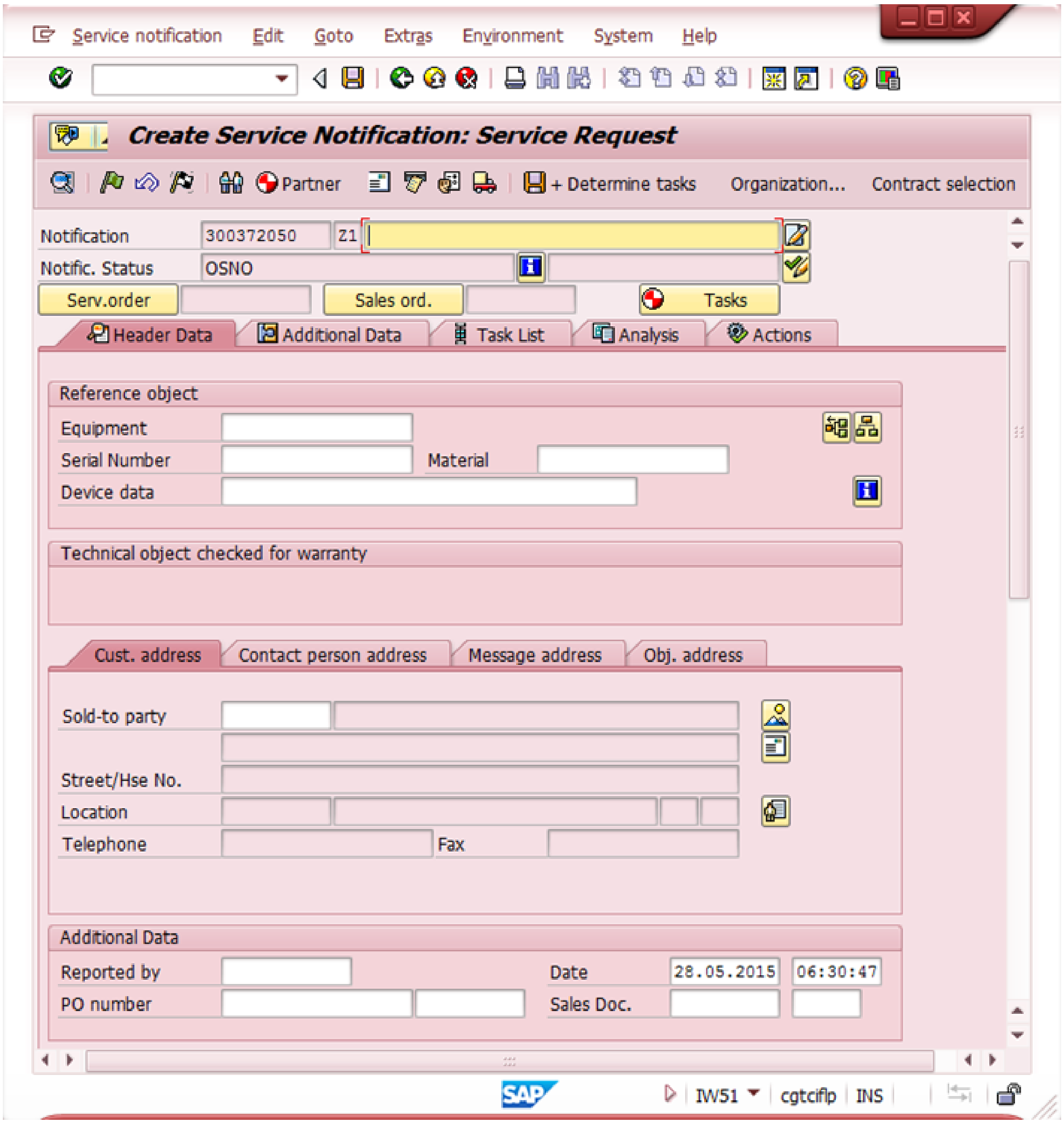


*__Figure 5.2.__ Create Service Notification screen in SAP, Header Data -tab.*

Behind the Additional Data –tab there is the possibility of adding a long text description of the failure or of the maintenance work once it has been done, shown in Figure 5.3. This field is used differently in the different countries or often not used at all. In Finland and the USA, the field is used to report information of the actual maintenance work performed on the machine. However, in England for example, the field is not used for information relating to the maintenance work, but rather as a field for internal communication.

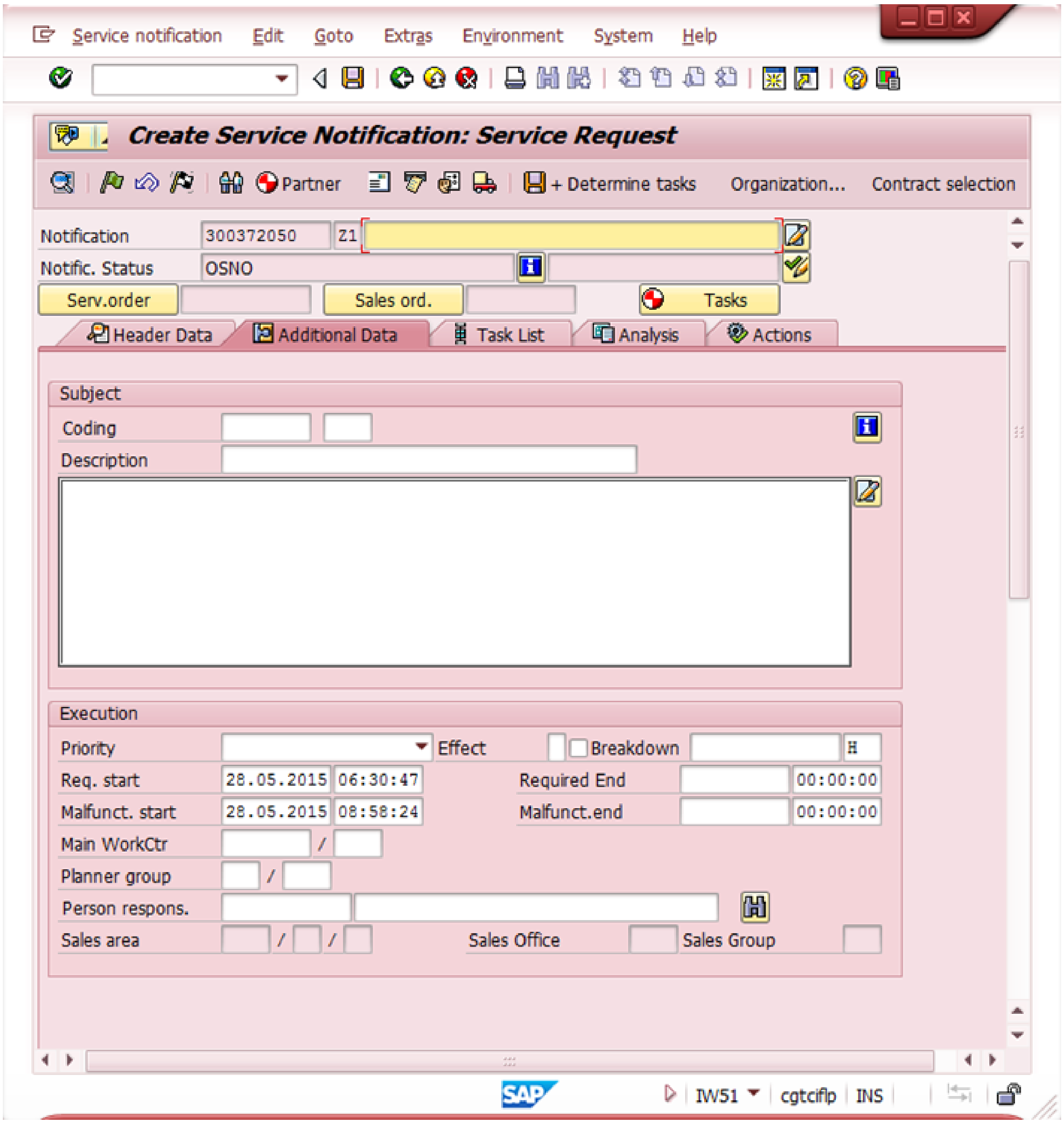


***Figure 5.3.*** *Create Service Notification screen in SAP, Additional Data –tab.*

To achieve a better layout for the Create Service Notification page we can bring the necessary fields to the top of the page and hide unnecessary ones. Reference information such as customer details is moved to the side. This principal of bringing what is important to the front and moving other information away applies to other transactions as well.

In this specific case of the Create Service Notification transaction, the Device data text field is only used in GB11 planning plant so for all others, it should be hidden. Furthermore, Purchase Order (PO) number is an important field for billing purposes so it needs to be moved top with Customer address information making space for it.

The fields behind the Additional data –tab (Figure 5.3) should be brought to the front tab (Header data) so they could immediately be accessed. This would remove the need for the Additional data –tab. Because the Analysis–tab contains fields to report failure codes and the cause of failures, it should be brought next to the Header data.

These changes would reduce the amount of screens needed by one (with the removal of Additional data –tab) and would bring most of the needed text fields to the opening screen. In actuality, it is more of a cosmetic change than something that would improve the situation greatly. The decrease from 35 to 34 screens is minimal.

### 5.1.2 IW31, Create Service Order

In Figure 5.4 the layout for the transaction Create Service Order is displayed. This transaction is used to report the progression of the maintenance work. In this module, the important information to be reported is to identify who is doing the maintenance and what type of maintenance it is (e.g. whether it is corrective, preventive or some other type of maintenance).

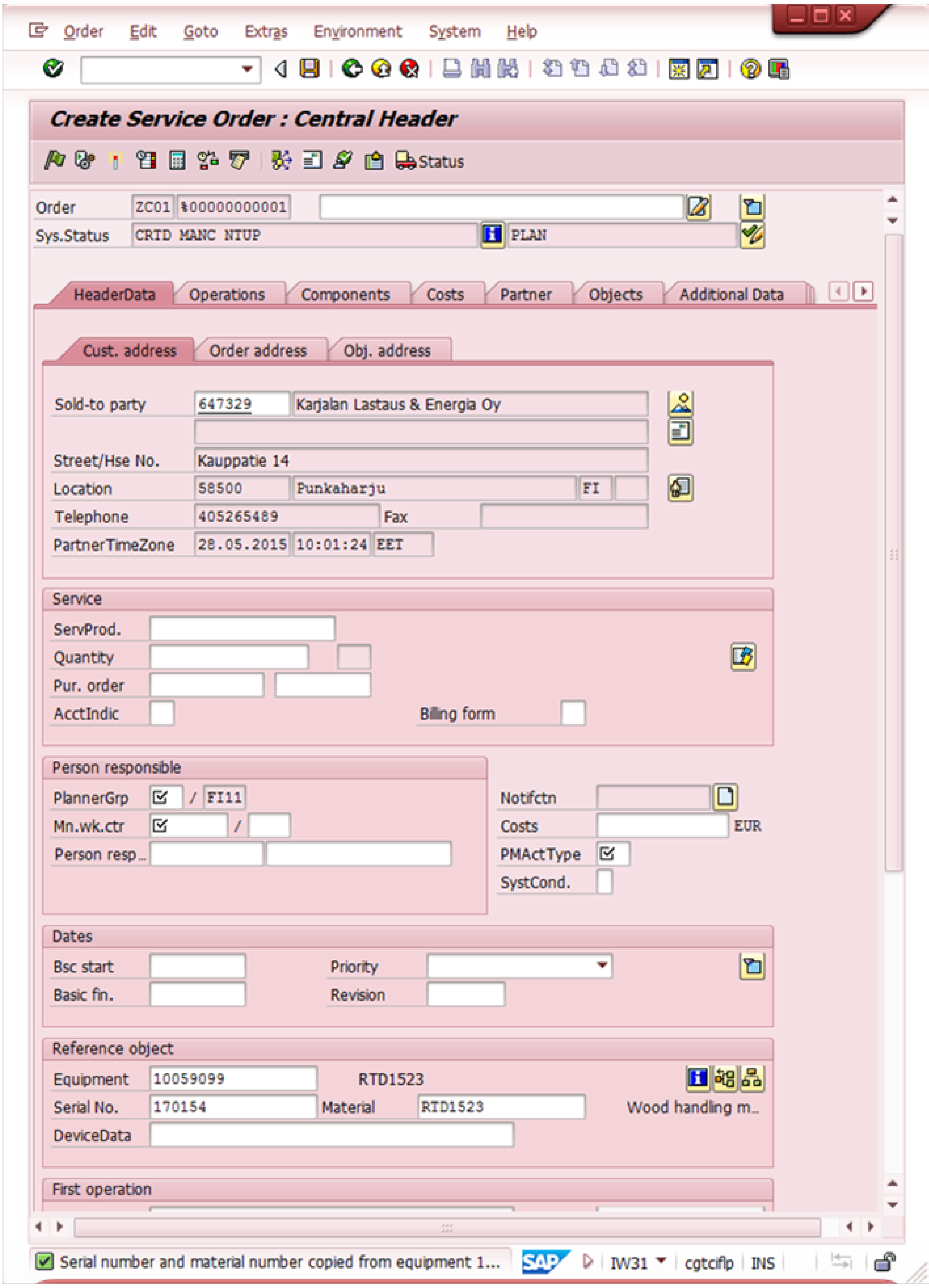


*Figure 5.4. Create Service Order screen in SAP.*

In the transaction screen shown in Figure 5.4 there are 3 text fields you must fill before you can continue. These fields are for planner group, main work center and PMActType which defines the type of service work done. Since they are mandatory they should be at the top of the screen instead of hiding them in the middle of other blocks which can’t be accessed before giving the required information.

This would mean the customer address block would have to move either downwards or to the side. This is information used only to verify you are reporting the work for the right machine and customer. One should take note that this address is the same as in the service notification and can therefore often be considered redundant.

With regard to blocks to be hidden, the block First operation that you get to by scrolling the transaction screen down shows the first operation listed in the operations list. It is automatically shown here so the user is not required to do anything, but even if it were hidden, you could see the information by clicking on the Operations-tab if needed.

### 5.1.3 Combining several transaction into one

A much greater benefit in the form of added usability could be obtained by combining several transactions under one transaction. An example of this is shown in Figure 5.5.

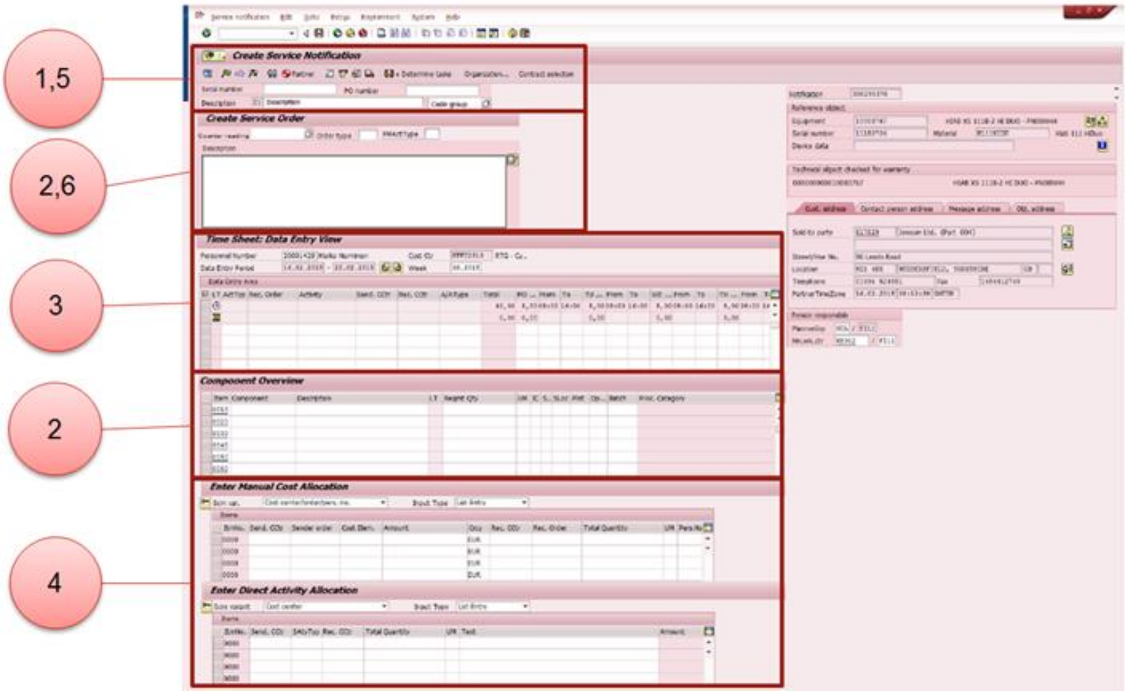


***Figure 5.5.*** *An example of several transactions combined onto 1 screen in SAP.*

The Figure 5.5 shows a layout of a new, fictitious module named “Report Maintenance Work” where 6 modules are combined into one. Those transactions are as shown on the figure: 1. Create Service Notification, 2. Create Service Order, 3. Register Hours, 4. Cost And Activity Allocation, 5. Report Technical Findings and 6. Create Measuring Document. To use an approach like this gives a much user-friendlier interface and a smoother reporting process as can be seen in Figure 5.6.

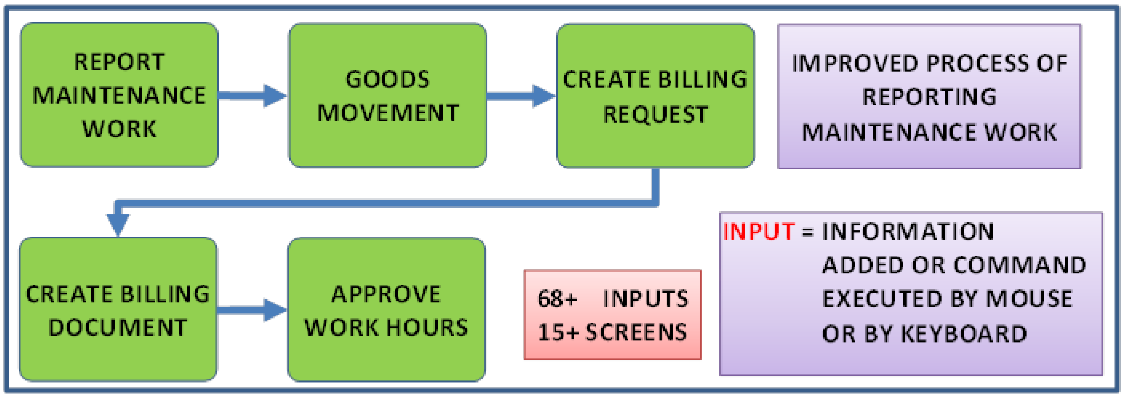


***Figure 5.6.*** *Data reporting process with the new "Report Maintenance Work" module.*

If it were possible to do this combination of 6 modules into 1, that alone would reduce the amount of inputs to almost half of what is currently required (68 vs 122 currently) and the amount of screens needed to input the information drops to a third (15 vs 46). This would no doubt lead to a significant save in time used in reporting and would free much of the resources currently used for reporting. However, a change of this magnitude requires a new type of software installed on top of the current system. One example of such software is SAP Screen Personas.

### 5.1.4 Software for simplifying the process

SAP Screen Personas is software added on top of SAP that provides a do-it-yourself approach that allows the modification of any SAP transaction or a group of transactions to streamline the way users interact with the system. For complex transactions with multiple screens, tabs, or tables, Screen Personas or similar software can be used to simplify the process and show only the information they need, in the proper context. It is also quite straightforward to implement.

SAP Screen Personas allows the recording of the data reporting process in SAP. Once the process has been recorded, the software creates a script that can be modified. This process is much like in other common programs such as Excel where you can also record your actions to create macros to help with common tasks.

In practice, SAP Screen Personas would be taken to the workshops, e.g. Vuosaari where they would add a work report to SAP. Screen Personas captures the process into a program script from where it is possible to identify the necessary text fields, dropdown lists, checkboxes etc. They are then compiled to the same screen with everything unnecessary removed. This way the user will only see what is needed and is not burdened with information he/she has no use for. This also reduces the amount of inputs dramatically. The process and its hopeful effect on the SAP user are shown in Figure 5.7.

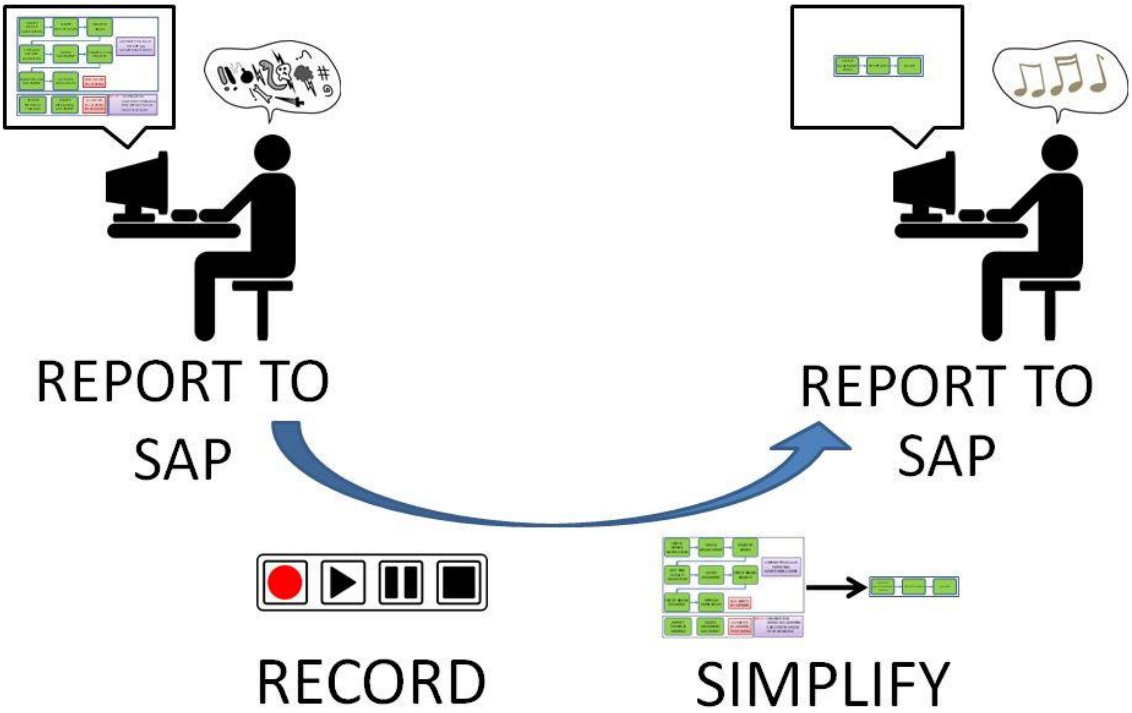


***Figure 5.7.*** *Use of SAP Screen Personas or similar software in simplifying the reporting process and the intended effect on the person reporting.*

The inputs will be reduced as shown with the Report Maintenance Work module example, because many of the 122 inputs (the 100 inputs currently used and the 22 inputs needed for the modules of Report Technical Findings and Create Measuring Document) are needed for transitioning from one screen to another. Also removing unnecessary information will lead to less screens needed which in turn will lead to reduced inputs.

What is also valuable is that the Screen Personas scripts can be designed individually for each country or workshop. This flexibility is a key factor when considering the diversity of reporting within Kalmar at different countries. Once implemented, users are able to modify the interface to best suit their needs without having to employ IT-professionals for modifications. This can be seen to lead to a reduction in IT-support costs. However, it should be noted that the more different the interfaces between countries, the more difficult it is for IT-support to assist them.

Moreover, if considering the possibility of reducing the current 122 inputs on 46 different screens to around 20 inputs on 3 screens, it will be much easier and faster to use. Therefore it should significantly cut down training costs as it will also be easier to learn for new users.

In addition to all the other benefits, SAP Screen Personas can be used with mobile tools such as smartphones and tablets. Since the technicians are carrying phones and tablets anyway, it should be considered a plus that the software does not need any separate hardware or a desktop computer to be used.

## 5.2 Mobile service solutions for reporting

Since currently work is reported first with pen on paper and later on transferred to SAP, there is an inevitable lag in the completion of the work report. This first step on recording on some other media other than directly to SAP can be seen as an unnecessary step that only takes up time from other tasks as it requires double the work compared to reporting directly to SAP.

Such unnecessary steps can be considered waste when thinking about a more effective way of reporting. One possible solution in removing this step is to start using mobile service solutions for reporting. This would mean tools such as smartphones, tablets or Personal Digital Assistants (PDAs) carried by the technicians would also be the media that is used to report maintenance work straight to SAP.

Furthermore, these types of tools could also help the technician in delivering maintenance. They could be used for example to go through a checklist of maintenance tasks, starting from studying the problem, collecting the right tools and reading the maintenance manual. The tools might be able to be used for reporting during maintenance, rather than only after. They could be tied into the actual maintenance process rather than just the post-maintenance process of reporting.

The use of these mobile service solutions has been explored in Kalmar Sweden where they have been in use by technicians working on the go, outside a permanent location such as a workshop. However the solutions used there have not been good enough to achieve set goals. In practice, the mobile tools have not been used during repair work, but rather at home after work. This way the mobility of the tool has little use and a desktop computer could be considered just as well.

Care must be taken towards the usability of the mobile tool in order to avoid making the technicians go from a bad reporting system to an equally bad or even worse. If such a mobile solution could be found that would be easy to use by anyone, it would eliminate the need for management to act as secretaries, typing the technicians’ work reports into SAP. The time saved would result in more time for actual repair work and would also decrease invoice lead time.

## 5.3 Automated data reporting

One way of reducing the need for reporting maintenance data would be to develop data transfer systems that would allow the machine to report its own failures. As more and more machines will have wireless data transfer tools, there will be more possibilities of automating the transfer of maintenance data from the machine straight to an ERP system such as SAP.

In Kalmar, wireless data transfer is a necessity for the rubber tired machines such as RTGs or Reach Stackers. Wired data on the other hand is used in more stationary machines such as the ASC's which are on rails and will therefore always be in the same area with the same facing. As a vision for the future, it should be possible to have the machines themselves create their own service notifications into SAP, maybe complete with failure, effects and cause codes as well.

## 5.4 Catalog profiles

One way to help reporting is to search and execute small improvements instead of aiming for large ones. One example of a possible small improvement is to define according to machine type what in SAP are called catalog profiles. This is discussed in the following chapters 5.4.1 – 5.4.3.

### 5.4.1 Current use

A catalog profile in SAP is a list of codes that locates failures to the sections and subsections of machines. Currently, Kalmar uses a general catalog profile that is the same for each machine type. As the machines differ quite a lot (e.g. an Automated Stacking Crane compared to a terminal tractor), the list contains more codes than would be necessary than if the codes were designed for each machine type separately.

The way Kalmar divides its machines into sections and sub-sections is based on the SAE J2008 standard for vehicle industry (SAE J2008). Kalmar maintenance manuals are also in line with the standard. The division of the general catalog profile currently in use at Kalmar is presented in appendix A.

### 5.4.2 Level of detail in catalog profiles

As mentioned, the division based on the SAE J2008 standard has been seen too generic to be used for all Kalmar machines. This is because while some Kalmar machines have all the sub-sections, some don't. For example the Rubber-Tyred Gantry Crane E-One2 does not have sub-sections "control system" or "common pneumatics". Moreover, the STS cranes do not follow the standard. This has led to situations where reporting of data at sub-section level is either found tedious or not possible (with STS cranes).

However as the current general catalog profile is based on the standard used in Kalmar maintenance manuals, it is well known by the technicians. A step outside the standard by introducing a new division and a new set of codes would likely bring confusion among them. Conformity has value in reporting and therefore there would need to be significant benefits to be obtained to make a set of new codes viable. Those kinds of benefits are not easy to see.

### 5.4.3 Catalog profiles unique for machine type

If decided to keep the current catalog profile failure codes, there is a step that can be taken to help the reporting of failure codes. That is to discard the general catalog profile and make unique profiles for each machine type. This would mean that when the failure code for the previously mentioned Rubber Tyred Gantry Crane E-One2 is input to SAP, the person could only choose codes applicable to it. The list would be shorter as it would not contain codes for the control system or common pneumatics. It would result in a slightly friendlier interface for the user.

The new catalog profiles defined according to machine type can be found in Appendix A.

## 5.5 Improving the structure of the work reports

If the use of open text fields is accepted as a best of the worst solution, it would be worthwhile to try and improve the structure of the reports. Then there would not be as many styles of reporting as there are technicians, but instead, in all reports the same types of information would be located in the same places. This would help the persons searching for information from the open text fields as they would know in advance where the information is written.

In addition, if the open text descriptions did have more structure, it would allow the better utilization of big data search algorithms that could be used to filter out the information even though written in an open text field. As currently customers are the ones who define the level of quality in work reports, it might be a good idea to ask them if they would prefer the reports to have a more set structure.

However, it must be stated that if the technicians did report using the intended tools in SAP, the work reports would automatically have more structure as the hour counter readings, spare parts, man hours etc. would all be reported in the proper fields from where they could also be searched effectively.

## 5.6 Hiring more staff

If it is found to take too many resources in terms of money and working hours to improve the current system, there should be an effort to try and look for new ways of dealing with the problems faced in reporting. As stated in Chapter 3, currently in Vuosaari reporting takes about 8 or 9 days each month (about 60-75 hours). The time spent on reporting is directly away from other responsibilities. This could be changed by hiring a person whose job would only be to act as the interface between the technicians and SAP, e.g. a secretary.

The secretary would then be responsible for writing all the work reports into SAP. In addition, if reporting was the responsibility of a single person with no other duties, he/she would have more control over the structure and language of the reports. The technicians could hand over their reports written in their native language and the reporter could make sure all reports are written to SAP with the same structure and in the same language by translating the information into English, for example.

Since in workshops like Vuosaari, reporting is not done as soon as the work reports arrive, but rather at times when enough work reports have arrived, the reporting could also be easily outsourced. All the reports would be sent outside the company to for example a translating company who would then either type the reports into SAP or send them back for the manager for approval.

This kind of approach would bring reporting costs visible and could also be used to employ new types of reporting such as instead of writing the reports they could be spoken and recorded and then sent to the secretary for transcription.

# 6. CONCLUSION

In this thesis, the data collection system of a container moving machine manufacturer, Kalmar, was studied. Kalmar uses an ERP system called SAP for the reporting of maintenance data. It was found that the current process of maintenance reporting is by far too complex and the current user interface does not help, but actually takes time away from the valuable work of maintaining machines. In addition, the extensive time spent on reporting to SAP does not produce high quality work reports.

The collecting of reliability data is important in order to evaluate the dependability or RAM (Reliability, Availability and Maintainability) parameters of products. The information can be used as a catalyst for product development, pinpointing specific dependability targets for machines and their sections and subsections. Furthermore, with an increased understanding of the way Kalmar machines fail, there is the possibility of optimizing preventive maintenance schedules and spare part inventory levels. Moreover, the amount of technicians needed to repair machines can be more accurately predicted, helping determine the right amount of technicians needed on standby.

While maintenance reporting in Kalmar is sufficient in detail albeit slow in speed for invoicing, it is of little use for dependability analysis. The information currently reported contains the bare minimum needed for the invoicing of maintenance work, but the information about the cause, consequence and timing of failure or the activities done to repair failures are either not reported at all or are reported in open text fields.

The study of the reporting system presented in Chapter 4 found an upside to the current process of reporting in that it leaves lots of room for improvement. The situation would be much grimmer if the system was functioning as expected with current results. However, the identification of the problems related to maintenance reporting can be used to develop the system.

Unsurprisingly, at the Vuosaari workshop the current process is experienced to consume too much time and effort. Technicians at the workshop feel the user interface has not been created with the purpose of effective maintenance reporting in mind. Reporting is not found to support maintenance activities, but to take time away from them. In fact, the time they use for reporting has increased by 40 hours per month after adopting SAP according to the site manager. It amounts to an increase of 200% in reporting time although repair work hours have only increased by 25% during the same time.

The 40 hour increase is not surprising since a person reporting has to give over 100 different inputs to SAP in order to complete the reporting process of one maintenance work. Unfortunately, the problem goes further than that. The number of screens is overwhelming with the inputs scattered across 36 screens or more. On average, it leaves about 3 inputs per screen. Exploring the problem even further, the screens contain unneeded information and unused input fields, forcing the user to search for the right fields from each screen.

To be required to use a complex reporting system such as the current form of SAP has a negative influence on employee satisfaction. Reporting is seldom looked forward to, but is instead seen as a tedious task that keeps the technician away from doing what he/she is really good at and prefers doing. This has the potential of reducing employee satisfaction and therefore employee retention.

As discussed in Chapter 2, a decrease in employee retention leads to a reduction in service quality and vice versa. Improvements to the reporting system and process are therefore called. Improvements will not only lead to better maintenance reports and for a better basis for RAM analysis, they will lead to more satisfied employees, improve employee retention and therefore customer retention.

To combat the poor usability of SAP, Vuosaari workshop has adopted new policies for reporting that in turn reduce the usability of the information from an analysis viewpoint. As an example of such a policy is the habit of reporting maintenance data into open text fields. While reporting in them saves the information of a single maintenance done, it makes it unfeasible to use the information for extensive RAM analysis as the information would have to be read one by one from the reports.

What is equally damaging is the practice of opening a single work order for a machine per month and then writing all maintenance done that month under that same work order. This way it is impossible to get an idea of how many times the machine has been repaired or preventively maintained without – again – opening notifications and work orders one at a time.

Furthermore, when discussing reports written in open text fields one must remember an important issue – language. Technicians writing work reports into open text fields use their native language for reporting – and not only their native language, but often some dialect which has terms and abbreviations unknown to translation software. This means it is practically impossible to understand maintenance reports unless the person reading the report is also a native speaker of the language. Even then it may be challenging to understand everything.

To reduce problems such as these and in order to make reporting less time consuming and achieve a sufficient amount of data to be analyzed, the reporting must be made as easy and quick as possible. This is so that it won’t take any more time away from the technicians than necessary. One way improvement may be reached is by new software added on top of the current SAP system – such as SAP Screen Personas which is specifically designed to help simplify the SAP user interface.

Other possibility is to adopt a new approach by utilizing mobile client tools that allow technicians to report as much of the work as possible during the actual work. If welcomed by the technicians, the mobile tools could reduce the time to report by giving them an easier way of reporting. In addition, the mobile tools could also be used to not only report work, but to assist the technicians in doing their work better by for example allowing technicians to browse maintenance manuals or call for help when needed.

Another way of helping technicians with reporting is to hire more help. By employing professionals whose only task is to make sure the reports are written into SAP on time and in the correct language and structure, much of the reporting tasks would be taken away from the shoulders of the technicians - and also from the persons currently transcribing pen-on-paper reports to SAP.

In all development, it is also important to make small improvements where possible. The development of catalog profiles tailored to different machine types is an example of this. They are a small step in the right direction and when small steps are taken they amount to larger steps and improve the flow of the reporting process. This is turn will have its own positive impact on employee satisfaction, service quality and therefore also customer retention and profit.

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# APPENDIX A: DIVISION OF MACHINES INTO SECTIONS AND SUBSECTIONS FOR SAP CATALOG PROFILES

Here is presented a division of machines into their sections and subsections based on the SAE J2008 standard for Recommended Organization of Vehicle Service Information for Interchange. This division shown in figures A.1 and A.2 is used in Kalmar maintenance manuals for all machine types except Ship-to-Shore Cranes which currently follow no standard in their division of sections and subsections.

The SAE J2008 based standard includes 12 machine sections and their subsections as shown in figures A.1 and A.2. It is currently used for all Kalmar machines in SAP. This is not the best case scenario since when compared to the maintenance manuals of the machines, some of the them do not contain all the sections presented in the standard. Therefore when reporting codes to locate the failure to a section or subsection, the person reporting is given the choice of entering information that does not apply to the machine.

As an example, the Kalmar Rubber-Tyred Gantry Crane E-One2 maintenance manual does not contain the chapters for control system or common pneumatics. However, they are still shown to the person reporting failures into SAP. By removing such instances of non-existing sections from the SAP failure location code groups (i.e. catalog profiles), the person reporting the information will be quicker to find the applicable codes.

However, there is variance in the maintenance manuals of machine types. For example, some Shuttle Carriers have all sections 1-11 in their manuals, only missing section 12 “Common Pneumatics”. However, in the Shuttle Carrier SHC 250H there is no section 2 “Transmission” either. Therefore you have to ask if all versions and revisions of machine types should have their own code group.

The more detailed the code groups the more care needs to be taken when implementing and maintaining them. Furthermore, the benefit of creating separate groups for Shuttle Carriers isn’t much. The difference is that for a Shuttle Carrier without transmission, the user chooses from 9 different sections instead of 10. When considered the average technician maintains different types of Shuttle Carriers, he still needs to choose from 10 options whenever a Shuttle Carrier with transmission needs maintenance.

Moreover, it can add to the confusion of the person reporting the data if he is given a different selection of choices depending on the type of the Shuttle Carrier he is maintaining. It is difficult to compare the user-friendliness of a conformed selection of 10 choices to a selection changing between 9 and 10 according to machine version. The author believes the list of selections should be kept at a constant 10 to not add any further pressure on maintaining the code groups for different types of machines.

| 1 | Engine |
|---|---|
| 1.1 | Instrumentation |
| 1.2 | Fuel System |
| 1.3 | Aux. Emission |
| 1.4 | Electrical motor |
| 1.5 | Mechanical |
| 1.6 | Intake/Exhaust |
| 1.7 | Cooling system |
| 1.8 | Lubrication |
| 1.9 | Control system engine |
| 1.10 | Ignition/heating |
| 1.11 | Start/stop |
| 1.12 | Engine aux. |

| 2 | Transmission |
|---|---|
| 2.1 | Instrumentation |
| 2.2 | CVT/Clutch system |
| 2.3 | Mechanical transmission |
| 2.4 | Hydraulic transmission |
| 2.5 | Electrical transmission |
| 2.6 | Lubrication |
| 2.7 | Cooling system |
| 2.8 | Control system trans. |
| 2.9 | Transmission aux. |

| 3 | Driveline/Axle |
|---|---|
| 3.1 | Instrumentation |
| 3.2 | Drive shaft |
| 3.3 | Kardanaxel |
| 3.4 | Transfer case |
| 3.5 | Hydrostatic drive |
| 3.6 | Electrical drive |
| 3.7 | Aux |

| 4 | Brakes |
|---|---|
| 4.1 | Instrumentation |
| 4.2 | ABS |
| 4.3 | Service brake system |
| 4.4 | Non-power assist system |
| 4.5 | Parking brake system |
| 4.6 | Speed retardation system |
| 4.7 | Trailer brake connections |
| 4.8 | Temp, clean, oil |
| 4.9 | Brakes aux. |

| 5 | Steering |
|---|---|
| 5.1 | Instrumentation |
| 5.2 | Power assisted system |
| 5.3 | Non-power assisted system |
| 5.4 | Steering aux. |

| 6 | Suspension |
|---|---|
| 6.1 | Instrumentation |
| 6.2 | Suspension |
| 6.3 | Tyre and rim system |
| 6.4 | Suspension aux. |

| 7 | Load handling |
|---|---|
| 7.1 | Instrumentation |
| 7.2 | Lifting/lowering |
| 7.3 | Protruding |
| 7.4 | Side shift |
| 7.5 | Positioning |
| 7.6 | Rotation |
| 7.7 | Tilt |
| 7.8 | Levelling |
| 7.9 | Load carrying |
| 7.10 | Other functions |

| 8 | Control system |
|---|---|
| 8.1 | Instrumentation |
| 8.2 | Monitoring |
| 8.3 | Error codes |
| 8.4 | Diagnostics |
| 8.5 | Setup |
| 8.6 | Software |
| 8.7 | Control system aux. |

***Figure A.1.*** *Division of machines into sections (1-8) and their subsections according to standard SAE J2008.*

| 9 | Frame, cab, fittings |
|---|---|
| 9.1 | Instrumentation |
| 9.2 | Safety/emergency equip. |
| 9.3 | Seat |
| 9.4 | HVAC |
| 9.5 | Wiper/washer system |
| 9.6 | Lighting system |
| 9.7 | Communication systems |
| 9.8 | Entertainment/com. |
| 9.9 | Glass/windows/mirrors |
| 9.10 | Cab structure, sups. |
| 9.11 | Cab interior |
| 9.12 | Frame |
| 9.13 | Body structure |
| 9.14 | Central lubrication |
| 9.15 | Paint/coatings |
| 9.16 | Frame, cab aux. |

| 10 | Common hydraulics |
|---|---|
| 10.1 | Instrumentation |
| 10.2 | Safety valves |
| 10.3 | Tanks and accumulators |
| 10.4 | Pumps |
| 10.5 | Hose, pipes and valves |
| 10.6 | Temp, clean, oil |
| 10.7 | Hydraulic aux. |

| 11 | Common electrics |
|---|---|
| 11.1 | Instrumentation |
| 11.2 | Electric protection |
| 11.3 | Batteries |
| 11.4 | Alternator |
| 11.5 | Distribution of el. |
| 11.6 | Communication |
| 11.7 | Electrics aux. |

| 12 | Common pneumatics |
|---|---|
| 12.1 | Instrumentation |
| 12.2 | Tanks and accumulators |
| 12.3 | Compressor |
| 12.4 | Hoses, pipes and valves |
| 12.5 | Filters, dryer, press. |
| 12.6 | Pneumatic aux. |

***Figure A.2.*** *Division of machines into sections (9-12) and their subsections according to standard SAE J2008.*

Therefore the author has defined unique code groups for machine types by removing only those sections that are nonexistant for all versions of a machine type. As an example, the shuttle carriers' (paired up with straddle carriers) failure location code groups contain the sections 1-11 because they can be found in the different versions. As section 12 is not found in any of them, it is removed from the group.

The same procedure is done for all machine types and the new failure location code groups (i.e. catalog profiles) presented in Table A.1. The sections to include for specific machine types are marked with an "X" while the sections to be removed are blank. Subsections are copied from the SAE J2008 based standard and not shown in the Table A.1. While the STS cranes do not follow the standard they are still listed in the table as a reminder of the fact.

***Table A.1.*** *SAE J2008 –standard machine sections included in catalog profiles of different machine types marked with "X".*

| No. | Section | Terminal Tractor | Straddle/Shuttle carrier | RTG | Log stacker | Automated Stacking Crane | Forklifts | Reachstacker | Ship-to-Shore crane |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Engine | X | X | X | X | | X | X | Does not apply |
| 2 | Transmission | X | X | X | X | | X | X | |
| 3 | Driveline/Axle | X | X | X | X | X | X | X | |
| 4 | Brakes | X | X | X | X | X | X | X | |
| 5 | Steering | X | X | X | X | | X | X | |
| 6 | Suspension | X | X | X | X | X | X | X | |
| 7 | Load handling | X | X | X | X | X | X | X | |
| 8 | Control system | X | X | | X | X | X | X | |
| 9 | Frame, cab, fittings | X | X | X | X | X | X | X | |
| 10 | Common hydraulics | X | X | | X | | X | X | |
| 11 | Common electrics | X | X | X | X | X | X | X | |
| 12 | Common pneumatics | X | | | | | | | |

X = Section with subsections included in catalog profile

One more thing to consider is that currently in SAP it is not possible to report failures at the machine section level (e.g. "Engine"). This can be an issue when technicians find it difficult to define failure locations at subsection level. It may lead to the code not being reported. Therefore the author thinks it should be made possible to report failures at section level. One way to achieve this, is to add to each subsection level the code numbered 0 and labeled "General" as shown for sections Steering and Suspension in Figure A.3.

| 5 | Steering |
|---|---|
| 5.1 | Instrumentation |
| 5.2 | Power assisted system |
| 5.3 | Non-power assisted system |
| 5.4 | Steering aux. |

| 5 | Steering |
|---|---|
| 5.0 | General |
| 5.1 | Instrumentation |
| 5.2 | Power assisted system |
| 5.3 | Non-power assisted system |
| 5.4 | Steering aux. |

| 6 | Suspension |
|---|---|
| 6.1 | Instrumentation |
| 6.2 | Suspension |
| 6.3 | Tyre and rim system |
| 6.4 | Suspension aux. |

| 6 | Suspension |
|---|---|
| 6.0 | General |
| 6.1 | Instrumentation |
| 6.2 | Suspension |
| 6.3 | Tyre and rim system |
| 6.4 | Suspension aux. |

***Figure A.3.*** *Division of sections into subsections according to SAE J2008 –standard on the left. On the right the same division with the "General"-option numbered 0 added.*

With the "General" code the technician is able to designate the failure code on the section level without required to report a code that doesn't describe the failure location well. The reason for giving the "General" code the number 0 is that by doing so, the SAE J2008 standard numbers for the subsections stay the same.

Since the STS crane maintenance manuals do not follow the SAE J2008 standard division, a unique set of codes is needed for them. Currently in STS maintenance manuals a drawing system is used where categories and codes are marked on the drawing as shown in Figure A.4. Descriptions for the numbered sections are found in figures A.5 and A.6. In total, there are 56 sections for the STS cranes which is excessive if considered that they should be picked out from a dropdown menu in SAP.

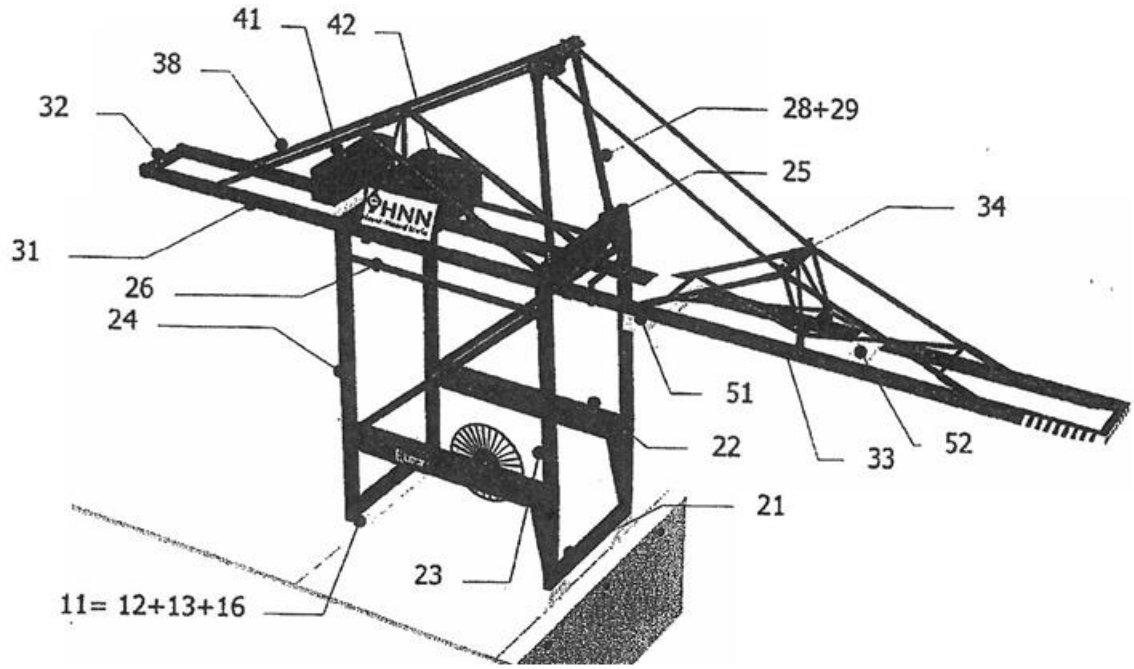


***Figure A.4.*** *Drawing in an STS maintenance manual showing STS sections.*

| GroepNr | Benaming | Name |
|---|---|---|
| 11 | Rijwerk | Travelling gear |
| 12 | Bogies | Bogies |
| 13 | Balanzen | Balances |
| 16 | Hoofdbalanzen | Main balance |
| 19 | Stormverankering | Stormanchoring |
| 21 | Rijwerkbalk | Sillbeam |
| 22 | Koppelbalk | Crossgirder |
| 23 | Poten waterzijde | Legs WS |
| 24 | Poten landzijde | Legs LS |
| 25 | Krammen | Portalbeams |
| 26 | Diagonalen | Ties portal |
| 27 | Vioolstuk en hangstang | Forestay |
| 28 | A-frame | A-frame |
| 29 | Pyloonkop | Pylonhead |
| 31 | Brugligger | Bridgegirder |
| 32 | Brugligger koppelbalk | Bridgegirder Crossgirder |
| 33 | Klapligger | Boomgirder |
| 34 | Kopklap + delta | Boomsheave support |
| 35 | Draaipunt klap | Boomhinge |
| 36 | Kabelrups óf Kabelkatrail | Powerchain or Festoon rail |
| 37 | Kabelstation | Festoon station |
| 38 | Trekstangen | Ties |
| 41 | E- huis | E-house |
| 42 | Machinehuis | Machineryfloor |
| 47 | Cabine | Cabin |
| 51 | Kat | Trolley |
| 52 | Hulp-kat | Secondary trolley |
| 53 | Katspanlier | Trolley tensioning winch |
| 54 | Skew installatie | Skew installation |
| 55 | Spreader | Spreader |
| 56 | Haakjuk | Hookbeam |
| 57 | Headblock | Headblock |
| 61 | Hijslier | Hoistingwinch |
| 63 | Katrijden | Trolleytravelling |
| 65 | Klaphijslier | Boomhoistingwinch |
| 67 | Inscheerlier | Reevingwinch |
| 69 | Overlastbeveiliging en trim/list | Overload and trim-list device |
| 71 | Trappentoren | Stairtower |
| 72 | Lift | Elevator |
| 77 | Borden en Stickers | |
| 81 | Berekeningen | |

***Figure A.5.*** *Explanation of number codes for machine sections 11 - 81 in STS maintenance manuals. Sections in Dutch (left column) and English (right column).*

| | | |
|---|---|---|
| 82 | Project management | |
| 83 | Klant | |
| 84 | Documentatie | |
| 85 | Montage | |
| 86 | Elektrische installatie | |
| 87 | Hydrauliek | |
| 90 | Conservering | |
| 91 | Transport | |
| 92 | Smeermiddelen | |
| 93 | Bouwplaats | |
| 94 | Product support | |
| 95 | CMV | |
| 96 | Restpunten & Overdracht | |
| 98 | Reservedelen | |
| 99 | QC & Afwijkingsraporten | |
| | | |
| | | |
| | | |

***Figure A.6.*** *Explanation of number codes for machine sections 82 - 99 in STS maintenance manuals. Sections are in Dutch.*

While there are many sections, the upside is that the current division is familiar to the technicians. However, as 56 codes is such a large amount it needs to be discussed if the amount should be reduced. This topic has been approached previously in Kalmar. The division for the STS cranes shown in Figure A.7 was made for Kalmar by a third party company. To create the division, the company studied maintenance manuals from Kalmar's STS cranes and guidelines from internal documents.

While this new division in Figure A.7 would bring a new set of codes for the technicians to learn, it would be easier to use in SAP as the technicians would first have to choose from only 9 sections and then at most from 9 subsections as opposed to choosing one section from the 56 that are currently used.

| 0 | General |
|---|---|

| 1 | Crane Travelling |
|---|---|
| 1.0 | General |
| 1.1 | Travelling mechanism |
| 1.2 | Storm pin structure |

| 2 | Portal |
|---|---|
| 2.0 | General |
| 2.1 | Sill beams |
| 2.2. | Cross girders |
| 2.3 | Waterside legs |
| 2.4 | Portal beams |
| 2.5 | Diagonals in portal |
| 2.6 | Forestay |
| 2.7 | Pylon |
| 2.8 | Pylon head |

| 3 | Beams |
|---|---|
| 3.0 | General |
| 3.1 | Bridge Girder |
| 3.2 | Boom Girder |
| 3.3 | Boom tip / lower sheave block boom hoist |
| 3.4 | Boom pivot point |
| 3.5 | Festoon rail / power chain |
| 3.6 | Festoon station /bridge girder backreach |
| 3.7 | Back tie (pylon head - bridge girder) |

| 4 | Houses |
|---|---|
| 4.0 | General |
| 4.1 | E-house |
| 4.2 | M-house |
| 4.3 | Cabin (operator, checker, boom hoist) |

| 5 | Trolley systems |
|---|---|
| 5.0 | General |
| 5.1 | Trolley structure |
| 5.2 | Spreader |
| 5.3 | General cargo hook |
| 5.4 | Headblock |

| 6 | Winch mechanism |
|---|---|
| 6.0 | General |
| 6.1 | Hoisting winch |
| 6.2 | Hoist ropes |
| 6.3 | Trolley travelling |
| 6.4 | Boom hoist winch |
| 6.5 | Boom hoist ropes |
| 6.6 | Reaving winch |
| 6.7 | Anti snag trim/list system |

| 7 | Frame/steelstructure |
|---|---|
| 7.0 | General |
| 7.1 | Stair tower |
| 7.2 | Personnel elevator |

| 8 | Measurement Systems |
|---|---|
| 8.0 | General |
| 8.1 | Electrical installation and lighting |

***Figure A.7.*** *Suggestion of division of STS cranes into sections and subsections. Division made for Kalmar by a third party company.*

## APPENDIX B: WORK REPORT FROM VUOSAARI WORKSHOP

**WO. LOMAKE**

ORRGOTEC

| | |
|---|---|
| TYONUMERO: | |
| KONEEN S/N: | Nosturi 3 |
| KÄYNTITUNNIT: | |
| VIKAKUVAUS: | Vaunu ei liiku/ mene puomille |

| HENK.NRO | PVM | TUNNIT |
|---|---|---|
| 10154 | 12.1.2015 | 1 |
| 20258 | 12.1.2015 | 1 |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

| MATERIAALIT | OSANUMERO | KPL |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
| 11 | | |
| 12 | | |

**TEHDYT TYÖT (TÄYTETTÄVÄ JOKA TYÖLLE!)**

Puomin köysien kuorma-arvo liian suuri puomin ollessa alhaalla. Muutettu ohjelmallisesti raja arvoja suuremmaksi. Laitettu myös lämmitys takaisin päälle kuorma-tappeihin. Selvisi myös että vaunu ei mene puomille> sähköhuone ylilämpöhälytys päällä. 2 ilmastointikoneikkoa mykkänä. Toinen heräsi pakko-ohjaamalla henkiin, toisesta käpsähti painekytkinkortin muuntaja. AFEn puoleinen rikki.

***Figure B.1*** *Typical work report from Kalmar workshop at Vuosaari harbor, Helsinki Finland.*

# APPENDIX C: CURRENT PROCESS OF REPORTING MAINTENANCE DATA, DETAIL VIEW

Figure C.1 shows the current process of reporting maintenance data. It is divided into modules shown as green rectangles with rounded corners. Inside the modules the actions needed to complete the module are shown. Each SAP module starts by an input of a transaction code shown inside a red rectangle after which the process follows the blue arrows inside the modules.

Blue rectangles inside the modules represent new screens for the user to see and inputs needed to advance are shown in red. Once all inputs are given, you advance to the next module in the direction of the blue arrows. The process shown in Figure C.1 is divided in two by blue rectangles. The rectangle at the top shows the current process of reporting at the Vuosaari workshop. Rectangle at the bottom contains transactions needed for effective RAM analysis. Figures C.2 - C.10 show the modules in greater detail.

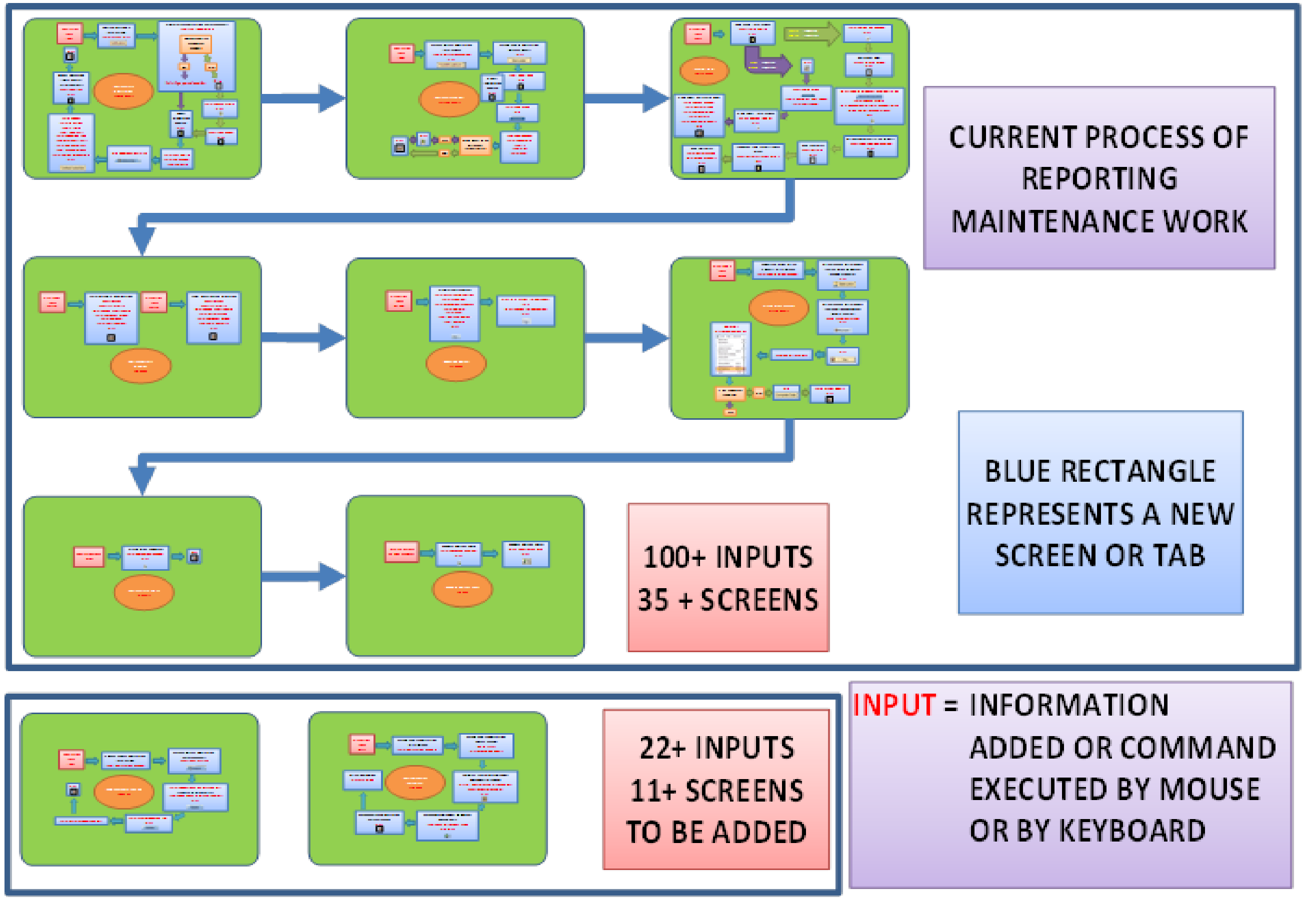


***Figure C.1*** *A detailed flowchart of the current maintenance data reporting process at Vuosaari harbor workshop, Helsinki Finland.*

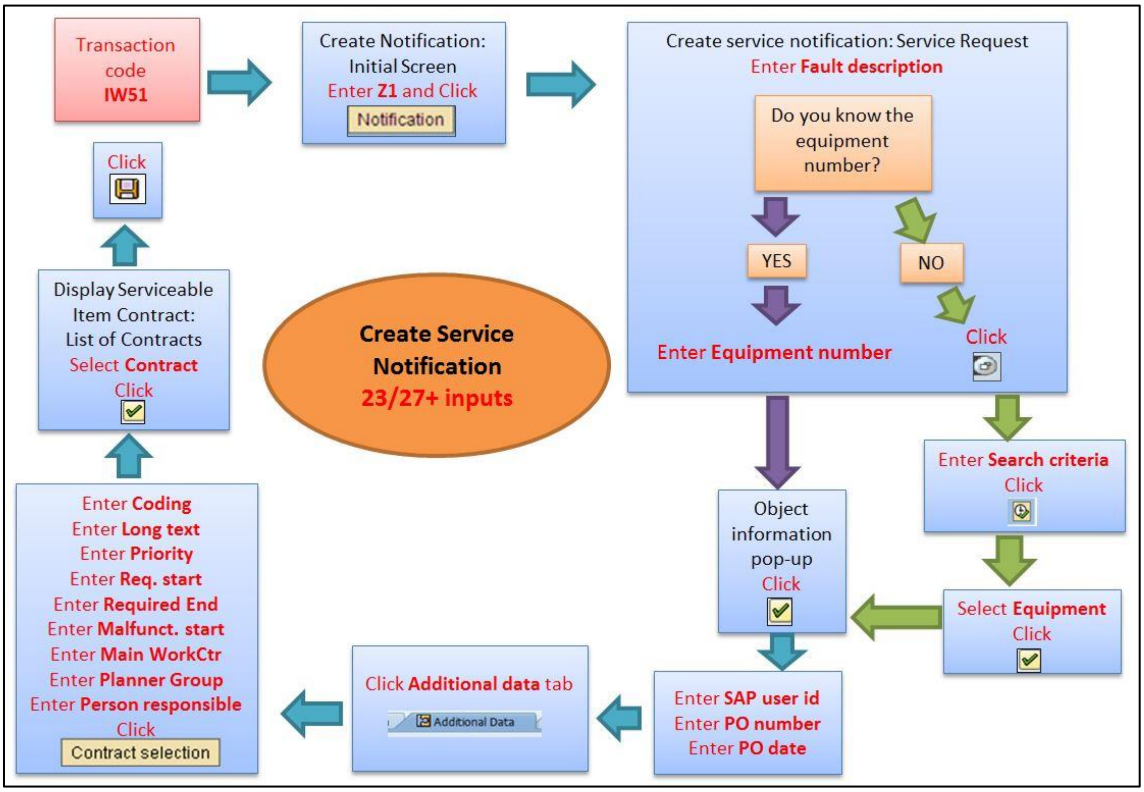


***Figure C.2.*** *Flowchart for the Create Service Notification SAP module.*

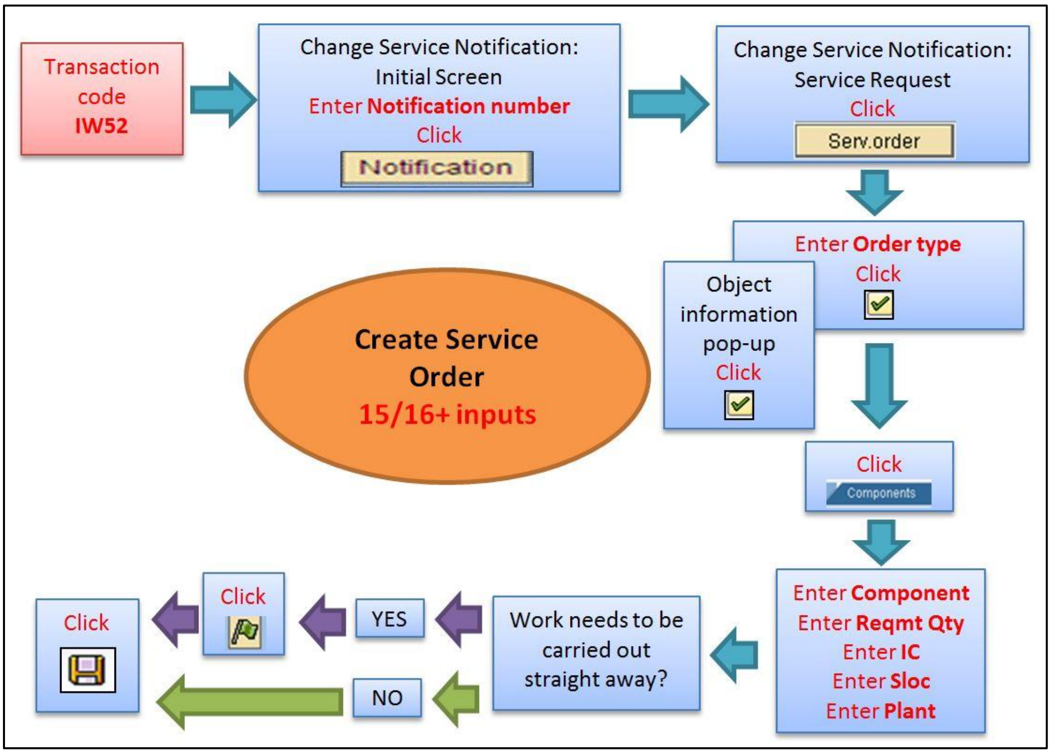


***Figure C.3.*** *Flowchart for the Create Service Order SAP module.*

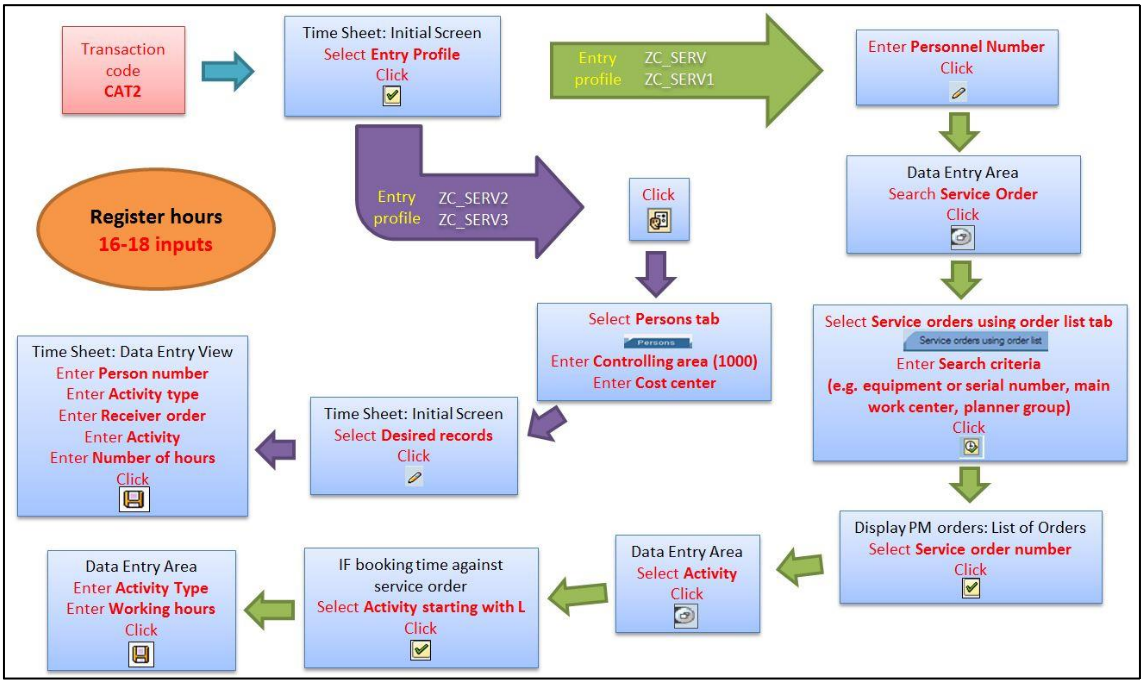


***Figure C.4.*** *Flowchart for the Register hours SAP module.*

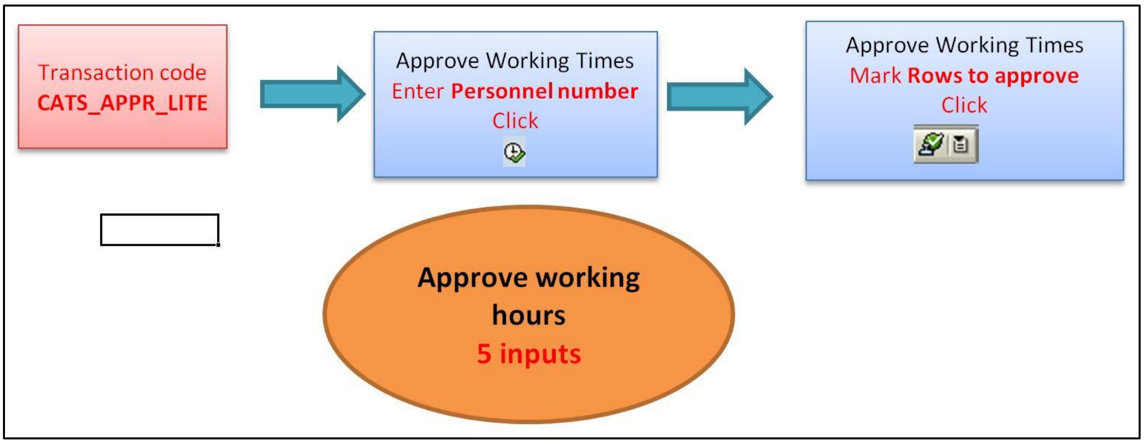


***Figure C.5.*** *Flowchart for the Approve working hours SAP module.*

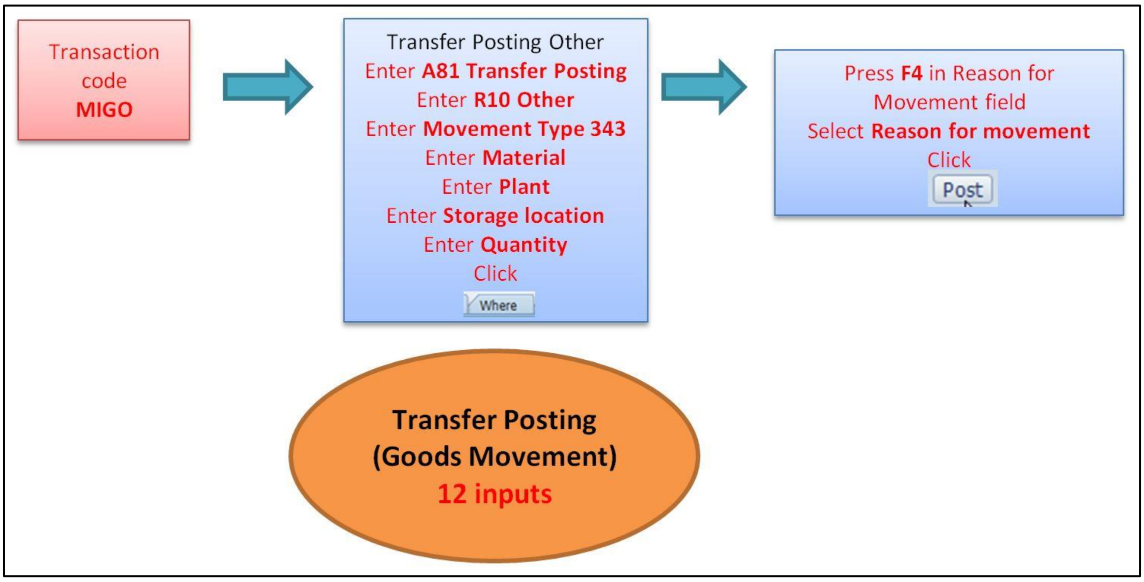


***Figure C.6.*** *Flowchart for the Transfer Posting SAP module.*

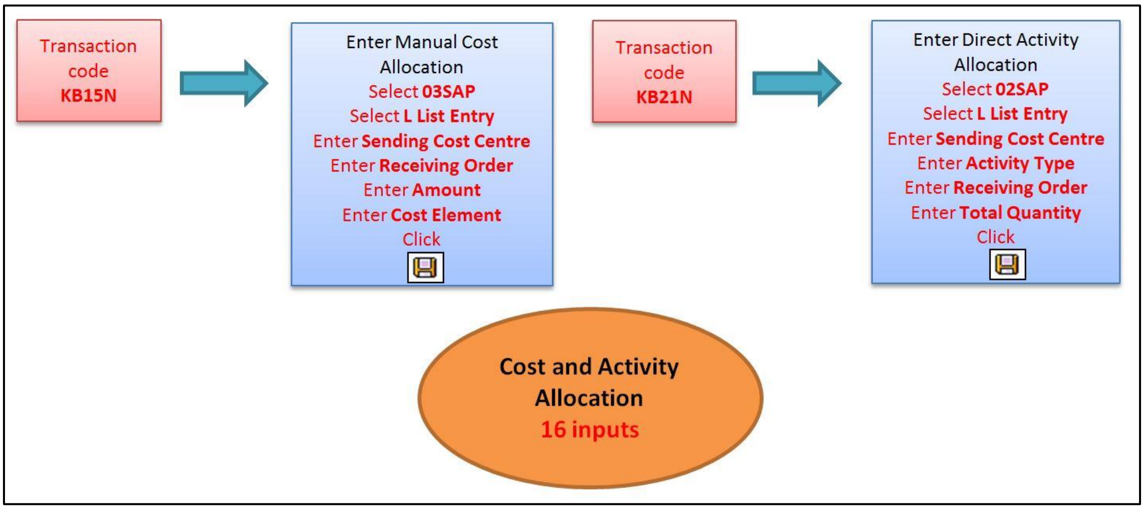


***Figure C.7.*** *Flowchart for the Cost and Activity Allocation SAP module.*

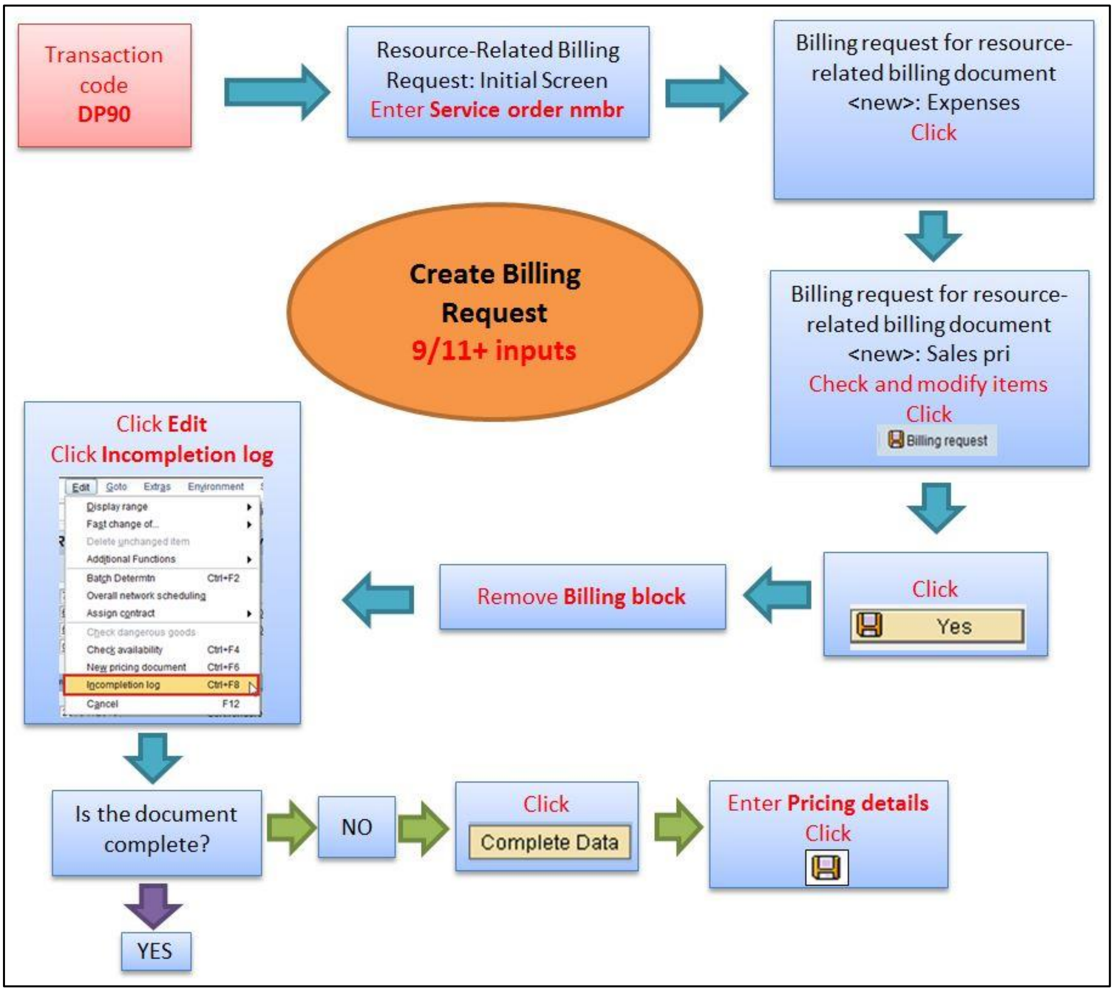


*Figure C.8.* *Flowchart for the Create Billing Request SAP module.*

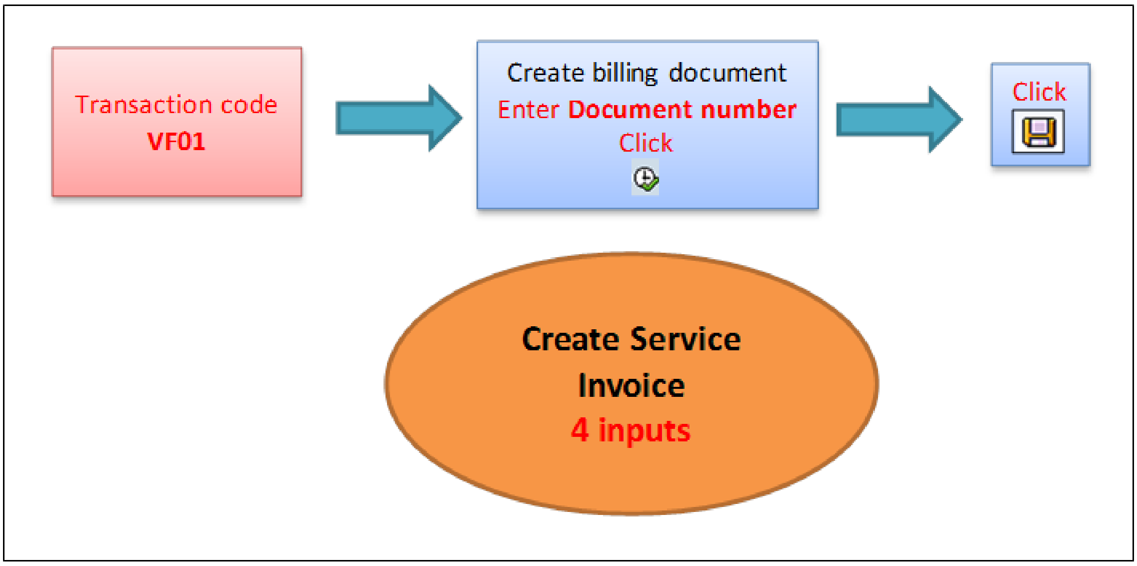


*Figure C.9.* *Flowchart for the Create Service Invoice SAP module.*

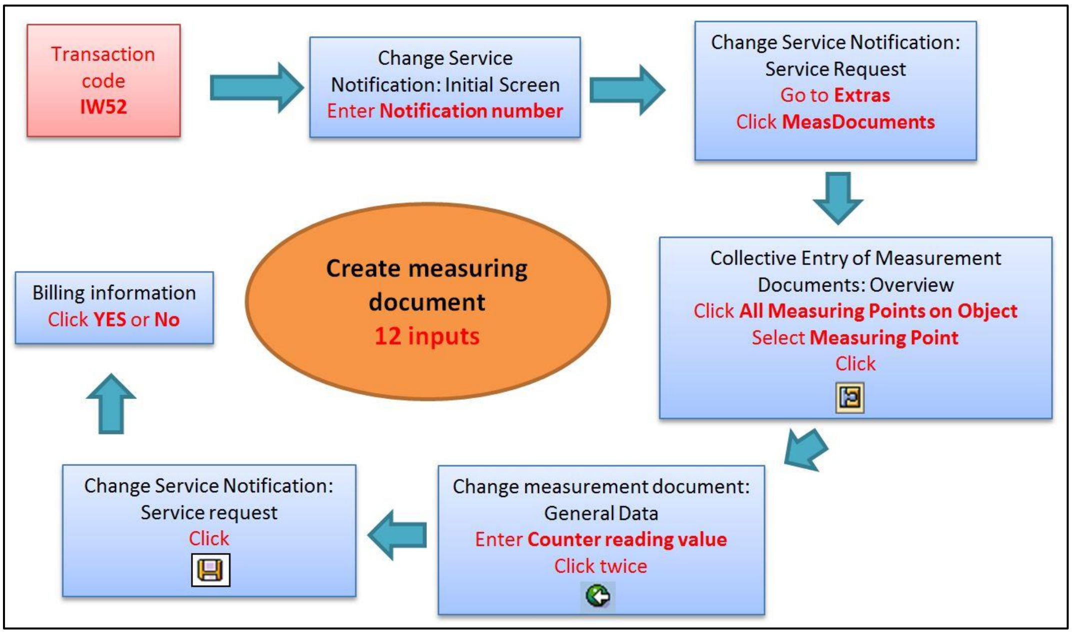


***Figure C.10.*** *Flowchart for the Create measuring document module.*

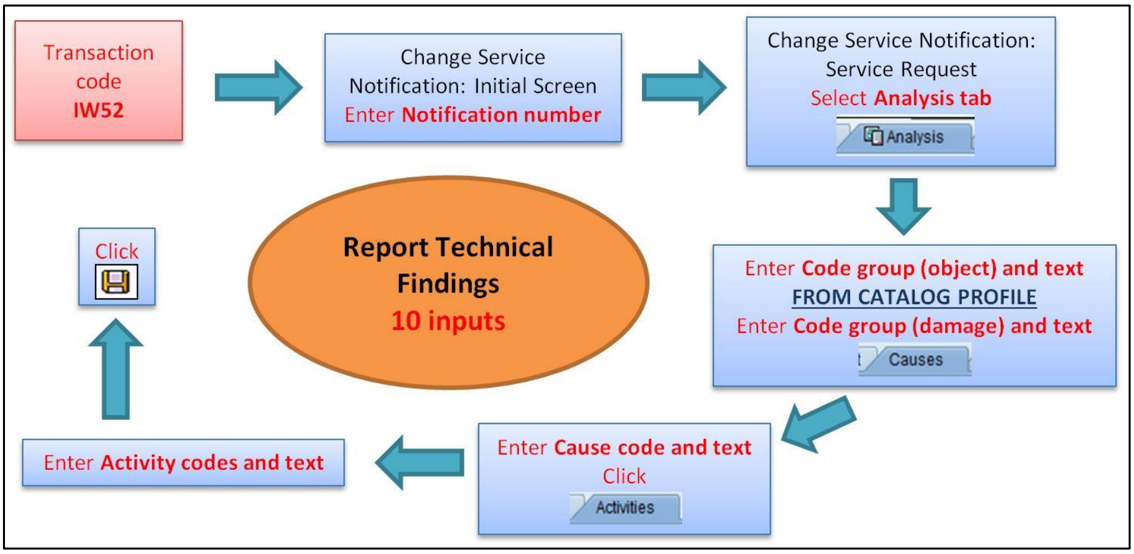


***Figure C.11.*** *Flowchart for the Report Technical Findings module.*